

Grant ARO DAAH04-95-1-0246: Wireless Distributed Multimedia Communications Networks for the Digital Battlefield –Final Progress Report, 31 December 1998

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13. ABSTRACT (Maximum 200 words) The Focused Research Initiative (FRI) group from Purdue University, the University of Illinois, the University of Michigan, Hughes Defense Communications (formerly Magnavox), and Hughes Network Systems (HNS) began work in July of 1995. Technical efforts are concentrated on multimedia wireless communication links, routing and congestion control, adaptive channel coding, adaptive antenna arrays, and the interface to and use of high speed networks. The FRI Group is uniquely integrating several Department of Defense Programs and the research and educational programs at three major universities, while achieving the benefits of collaboration with industry and the military. The FRI program has fostered and encouraged collaboration and technology exchange among the universities, industrial research groups, and the Army laboratories. Progress has occurred in the area of determining military requirements and using those requirements to guide basic research.				
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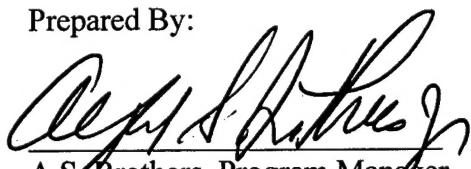
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Fri Final Report

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Introduction – the Digital battlefield

“The very nature of future operations will place great demands on the signal community. The digitized force will rely heavily on information and information systems support. The warfighter requires highly mobile command posts, situational awareness, dissemination of sensor data and imagery products, telemedicine, multimedia services, and total asset visibility. A robust and reliable C⁴ architecture is crucial in meeting these requirements.”¹

In contrast, “Today’s information system support infrastructure was designed and built to accommodate the requirements for voice and low speed data. As warfighter C⁴ requirements grow, network services and throughput, required to meet this demand, continue to increase. The currently fielded signal support infrastructure is incapable of fulfilling these growing C⁴ requirements.”²

The growth of these services, from 16 kbps to 45 Mbps, is shown in figure 1. The infrastructure must be interoperable, scalable, and upgradeable. Additional requirements are still developing as both the force structure and the mission requirements are reviewed to meet future fighting needs.

Figure 1. Increasing Requirements and Competition for Throughput

16 kbs
Voice & Still Video

56 kbs
Video & Batch Imagery

T1 (1.544 Mps)
Full Motion Video
Real-time Data
Still High Resolution/Imagery

45 Mbs
Real-time Multimedia

Background

Definition of the Digital Battlefield

The concept of the digital battlefield requires digitization of all the information on the battlefield needed for the conduct of battle and of mission accomplishment. This information ranges from soldier’s voice reports to satellite reconnaissance imagery and sensor video. The digitized information is stored in computer databases distributed across the battlefield.³ Software is used to extract information needed by a tactical commander, logistics commander, or individual soldier from the databases and to reformat, filter,

and fuse the data to forms useable for each particular function thereby reducing information overload.³ Functions include command and control, target detection and recognition, planning, analysis maps and overlays, intelligence, logistics, personnel, and position location.^{4,5} Wireless, distributed communications networks are required to acquire information from sources and to transmit it between databases and battlefield entities.⁶ Computer hardware technology is adequate for this job, however, software and wireless network technology are not. Technology for wireless, distributed multimedia communications networks must be found to support the multimedia transmission of speech, video, high-resolution maps and overlays, and other digital data in a highly mobile military environment requiring low probability of intercept and jamming resistance.

“A non-digitized division employs about 1300 computers. Considering requirements described in The Army Modernization Plan, The Army’s Enterprise Plan and Force XXI Advanced Warfighting Experiments, a fully digitized heavy division will employ over 5000 computers. Additional requirements will continue to emerge and the demands on the existing bandwidth will increase. The signal corps must provide an information system that is interoperable, scaleable, and flexible enough to allow rapid changes in throughput to accommodate the increasing requirements of the warfighter. The requirement to provide secure C⁴ network reliability and support must be met while minimizing the impact on the force structure.”⁷

There are a series of very unique problems that face the soldier on the digital battlefield. One of these is the dependence on batteries for self-contained electrical power. “Battlefield sensor platforms such as unmanned aerial vehicles, as well as individual soldiers, rely on batteries on increasingly long missions”, explains Dr. James Freebersyser. “The problem is batteries aren’t getting better”, Freebersyser admits.

“Electronics that run on batteries are fundamentally different in commercial and military applications, Freebersyser points out. Commercial electronics normally run on batteries for 18 hours before recharging. Military electronics, however must run for 72 hours between recharges – four times as long as commercial systems.”⁸

A potential Solution

Dr. Wayne Starke offers a potential solution to the battery power problem. “One of the most promising techniques developed under the MURI program is the turbo coding technique for spread spectrum radios. Turbo codes have been known for years, and are based on a mathematical technique developed in France, Dr. Wayne Starke, of the University of Michigan, says.”

“The key advantage of using the turbo coding technique is a transmitted power reduction of 6 decibels (dB), Starke says. It can handle interference in a better way than other coding techniques so you don’t need as much power.”⁹

What is the environment for military operations of the future?

“Military operations in the twenty-first century will be conducted in an increasingly information-rich environment. The application of detailed information about the theater of operations (location, composition, and maneuvers of hostile, neutral and friendly forces) will greatly increase the effectiveness of US forces. To change data into information, sensor data and field reports must flow to analysis centers for processing and then to the users in a form they can digest and apply easily. The increased knowledge provided will allow US decision-making to occur more rapidly than that of the enemy and to immediately take advantage in the battlefield. Through these mechanisms, information becomes a force multiplier that maximizes the effectiveness of deployed troops. But if information is to do all of this, it must be delivered from anywhere on the globe to the battlefield users, requiring communications systems to deliver this information that reach all force levels throughout the theater. This communications system must also deliver commands to warfighters and allow information transfer and support requests from warfighters back to commanders and support centers. In essence, all combatants, their communication, and support elements must be connected by a secure, robust, global grid of communications.

"However this "global grid" today is less than perfect, particularly in the forward areas of the tactical theater. Much of the military communications infrastructure that is currently in the field or being fielded is heavy, large and not transportable enough to keep up with rapidly maneuvering forces. Its deployment to a rapidly developing tactical theater is dependent on scarce air and lift capability.

"What is needed is a new communications capability that is light-weight, rapidly deployed, and requires minimal logistic support in the theater. The new capability must be able to provide communications connectivity to isolated forces, which are on the move (truly mobile). It is also important for it to provide connectivity to the legacy communications equipment found in the Services today and still being fielded."¹⁰

Environment of the Battlefield

The communication battlefield is comprised of many diverse elements. These elements include GBS, DirectPC, DirectTV, Airborne Nodes, Spaceborne nodes, and individual Ground components such as radios, computers, antennas, LAN and WAN systems. The use of these elements provides the redundancy and reliability needed to support the warfighter, no matter the battlefield conditions nor the distance between recipients.

The battlefield requires immediate communications capability, addressing uniquely to both units and individuals, and methods to reduce the vast amounts of data into useful and directly applicable information. The battlefield is a very fluid operation and instant coverage of the situation and instant relay of that coverage is paramount. Figure 2 depicts the overall view of the Warfighter's Internet Concept that provides a self-organizing Mobile, Wireless Network Backbone. This concept includes ground-based airborne and spaceborne components to provide the coverage and connectivity required for the highly mobile fighting force. A part of that structure is the airborne node.

Airborne Nodes

Airborne assets can provide both optical and SIGINT reconnaissance. The airborne node can therefore be the eyes and ears of the fighting force as well as the relay of timely intelligence information.

"Another way to view the use of the airborne communications assets is as an overlay communications supplement in conventional force deployments. The airborne nodes provide extensions of existing-theater communication systems to highly mobile or separated forces at or beyond the forward line of troops (FLOT). In this context, it is important that the Warfighter's Internet connect with the lower-echelon ground communications networks found at the edge of the battle, such as the Tactical Internet. In addition to servicing these isolated forces, the airborne network can provide alternative connectivity to substitute for deployed MSE equipment which is unable to make a node connection due to terrain, enemy action, mobility, or equipment failure."¹¹

WIN ACN capabilities

These broad goals have been translated into a list of capabilities for the ACN. The ACN capability should include¹²:

- (1) A modular communications node payload with gateway capability to support and interconnect a JTF, ARFOR, corps, or division that has both legacy and state of the art communications systems.
- (2) A robust antenna system, versatile power suite, and modular communications package to support rapid reconfiguration on a mission by mission basis, as communication priorities change. All components on the ACN should be capable of integrating leap ahead technology, as it becomes available.
- (3) Range extension (retransmission) of SINCGARS, EPLRS, UHF surrogate satellite, MSE, and JTIDS, as well as a limited gateway capability between SINCGARS and UHF satellite.

- (a). The ACN must be capable of performing retransmission for CNR/SINGARS nets. An airborne gateway between SINGARS and UHF Single Channel TACSAT will provide on-the-move capability for mobile platforms, without the need for high profile, directional auto-track TACSAT antennas.
- (b). The JTIDS provides near-real-time air defense engagement operations information that must be accessible by air defense artillery (ADA) units during all phases of an operation. JTIDS relay capability will extend connectivity between widely dispersed ADA task force elements and the joint air battle players. The ACN will augment other JTIDS relay, including Airborne Warning and Control System (AWACS), in providing JTIDS range extension.
- (c). EPLRS is used to broadcast situation awareness data. The relay will link enclaves that are beyond line of sight.
- (d). MSE relay will connect widely dispersed signal nodes on the battlefield.
- (4) Reach-back capability with digital cellular phones to support early entry and major offensive operations. (Cellular phone services may be limited because COTS cell sites are large and heavy, and there is at present no incentive for the commercial industry to downsize.) Reach-back communications will consist of a satellite link with minimum data rate of T1 (1.544 Mb/s).
- (5) A Communications Control Element (CCE) capable of switching frequencies, hopsets, and crypto variables by remote control from the ground. An onboard capability will allow for preprogrammable frequencies, hopsets, and crypto variables as well as Over-The-Air Rekey (OTAR) of hopsets and crypto variables.
- (6) Onboard Communications Manager/Controller (CMC) to increase the number of gateways to provide truly seamless connectivity to link users of dissimilar systems. The CMC is perhaps the most crucial capability for proper operation of the ACN. The CMC must perform the following functions:
- a. Ensure Inter-connectivity between/among all on-board communications services/equipment.
 - b. Manage in flight service priorities, frequency assignment, net initialization, communications security (COMSEC) key assignment, antenna pointing, with input from ground-controllers of ACN.
 - c. Be responsive (external to any resident control logic) to the ground controllers of the ACN payload, not to the airborne platform controllers.
 - d. Dynamically access and reallocate unused communications channels on the ACN.
 - e. Provide gateway connectivity and data format conversions for dissimilar joint radio systems (i.e. JTIDS to EPLRS, EPLRS to PLRS, HaveQuick II to EPLRS, etc.)
- (7) Range extension for Army and joint video teleconferencing.
- (8) LPI and LPD communications and store and forward e-mail for SOF and conventional elements that operate deep in enemy territory.
- (9) GBS relay to provide broadcast communications on-the-move to support tactical users with omnidirectional antennas and low powered receivers. TMD and NBC warnings can be uplinked to the ACN and rebroadcast to miniature pagers on the ground.
- (10) Flyaway transit case UAV Launch and Recovery (LRE) element. This miniaturized LRE can deploy early in a contingency operation, and allow in-theater mission controllers to direct the ACNs.
- (11) Cross-linking between multiple ACNs to cover an entire theater of operation.
- (12) The ACN must operate in secure and non-secure modes.

(13) The ACN must be technical architecture compliant to insure joint interoperability with joint and service objective architectures.

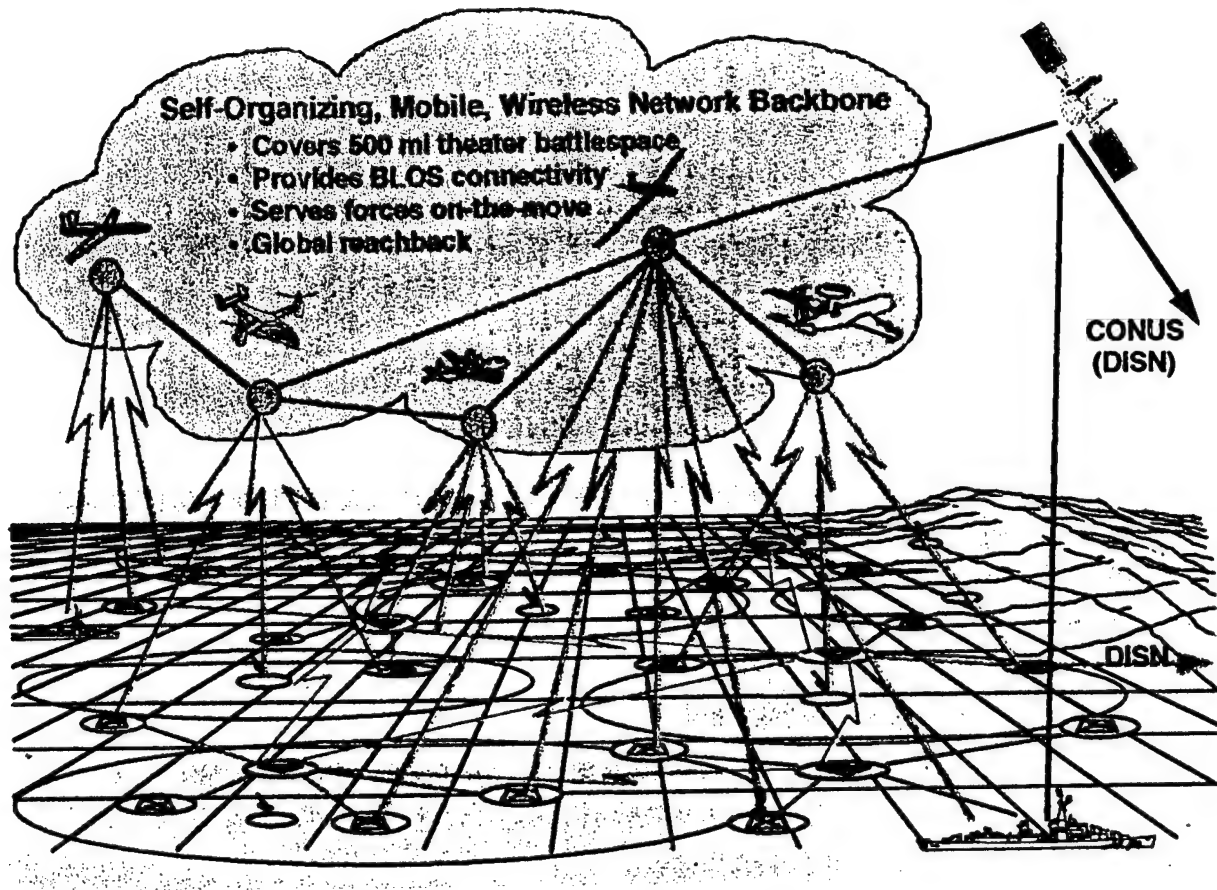
(14) The system must be compatible with WIN protocol and standards for switching and subscriber services.

WIN ACN Capabilities Matrix

Many of these capabilities are reflected in the requirements listing of this FRI. Communication connectivity and assured service are the underpinnings of these capabilities. This matrix shows the relationship between the ACN capabilities desired and the FRI listed requirements.

Capability Number (pages 7-9)	Requirements (page 47)
1. Capability to support and interconnect both legacy and state of the art communications	52, 199
2. Capable of integrating leap ahead technology	193, 195, 200, 201
3. Range extension (retransmission)	20, 128, 131
4. Reach-back capability with digital cellular phones; minimum data rate of T1 (1.544 Mb/s)	75
5. Communications Control Element (CCE)	24, 56
6. Onboard Communications Manager/Controller (CMC)	27, 50, 55, 56, 57, 58, 59, 63, 64, 66, 187
7. Range extension for Army and joint video teleconferencing	68, 76
8. LPI and LPD communications and store and forward e-mail	53, 60, 61, 77, 129
9. Provide broadcast communications on-the-move	4, 25, 26, 31, 62
10. Flyaway transit case UAV Launch and Recovery (LRE) element	
11. Cross-linking between multiple ACNs	10, 21, 128
12. Operate in secure and non-secure modes	27, 50
13. insure joint interoperability with joint and service objective architectures	44, 195, 196, 202

Figure 2 - Warfighter's Internet Concept¹³



Digital communications as a multiplier; Do more with less

As the size of the fighting force is reduced other means must be used to achieve military superiority and dominance. Communications is the multiplier. We must achieve more connectivity with less equipment. We must reduce the legacy equipment and upgrade our force with new digital systems.

“Army leaders are trying to phase out their present Mobile Subscriber Equipment (MSE) and its Tri-Tac communications systems, which represent 1970s technology. They want to replace MSE and Tri-Tac with the Warfighter Information Network 21 to achieve economies from a single, newer-technology system....”

“Army leaders are also trying to trim the size of each of their divisions from 18,500 to 15,000, beginning with the 4th Mechanized Infantry, by reducing the requirements for combat service support personnel.”¹⁴

Commercial capabilities explored

In achieving the reduction in equipment components, the military looks to modernizing its force structure using newer technologies. These newer technologies are emerging from the commercial sector.

“All agree that the dynamic commercial telecommunications industry holds at least some of the solutions. Army officials have already begun using terrestrial and space-based commercial off-the-shelf (COTS) systems spanning the HF and VHF bands devoted to military command and control.”¹⁵

Tactical Internet as a Battlefield Solution

“The Warfighter’s Internet contributes in several ways to information flow on the battlefield, and is synergistic with other theater communications systems in the process. Of course the obvious utilization of the Warfighter’s Internet is for beyond line-of-sight (BLOS) connectivity for theater-wide networking with global access. This capability would be utilized by Small Unit Operations for C², support requests, and for ISR data dissemination and requests. ISR products may also be delivered to the theater by the Global Broadcasts System/Battlefield Awareness Data Dissemination (GBS/BADD) system to locations equipped with the standard GBS microwave receive terminal and Warfighter’s Associate (WFA) processing system. But for forward and lightly armed troops, the essential ISR products can arrive through multicast messages over the Warfighter’s Internet from the WFA database or through queries of that database by the warfighters. Alternatively, a special T1-rate broadcast might be made (at a frequency around one GHz) of selected BADD information from the ACN airborne nodes to receivers that could operate while on the move using omnidirectional antennas.”¹⁶

ACN – A Communications Extension

The airborne communication node (ACN) provides an extension to the communication range and capability on the battlefield. The unique characteristics the ACN provides include:

1. UAV or other means to provide retransmission capability or an airborne cell site
2. FOV problems with airborne node (overlapping coverage possible)
3. Manned aircraft also possible
4. AOI – area of interest
5. Secure networks or sub-networks
6. An extension of the Corps commander’s communication capability
7. Available when specific satellite coverage is not available
8. Non shared asset for the commander

“The airborne nodes used for the Warfighter’s Internet (WI) include (but are not limited to) Airborne Communications Nodes (ACNs) on Global Hawk HAE UAVs flying at 65,000 ft. The Global Hawk is

particularly effective for theater operations because of its altitude (coverage) and endurance. The ACN, in addition to hosting the WI communications equipment carries other equipment to service legacy radios in the tactical theater (e.g., SINCGARS, LOS UHF, EPLRS, JTIDS). The ACN equipment may also include the T1 rebroadcast of selected BADD traffic and the ability to provide wideband relay between MSE node centers or between RAPs (Radio Access Points, tracked vehicles equipped with the High Capacity Trunk Radio, HCTR). Other WI nodes may also have the capability to connect directly with RAPs. Interconnects between the WI equipment and other ACN equipment can take place on board the ACN platform and/or through the MSE or DISN. Both the ACN and the WI would make use of the communications satellite terminal on board the Global Hawk to provide global reach back connectivity, so that an in-theater command center would not be required for their deployment.”¹⁷

DTV – Digital Television

Digital television (DTV) is the name given to a proposed new terrestrial broadcast system. The system will provide both HDTV (High Definition Television) and SDTV (Standard Definition Television) pictures. HDTV refers to the highest resolution formats within the standard, which provides approximately 2 million pixels per frame, or approximately 8 times the resolution of an S-VHS tape. SDTV provides approximately 300,000 pixels per frame of about 20% more than an S-VHS tape. SDTV will have approximately the same resolution as Digital Satellite, DVD, and new digital cable TV signals.

A DTV broadcast is “digital”. An analog carrier is modulated with a digital signal that contains the video picture, sound and sub-code data. HDTV requires more broadcast spectrum than SDTV. Each broadcaster can provide one HDTV broadcast or up to 6 SDTV broadcasts at a time.

DTV commercial capability

The following are a sampling of increased capability with DTV:

1. 1.45Gbps data transmission rate possible
2. 36 MHz bandwidth transponder can provide multiple data channels as well as DTV capability (HDTV and SDTV–Standard Definition TV). 6 channel broadcasts are possible (multicast systems).
3. Secure transmission possible with encryption for data and other services
4. System is available for worldwide operation – satellite orbit location and FOV dependent. Relay satellites are possibilities to extend capabilities.
5. Commercial parts and processes can be adopted for military uses – available in 2006.
6. Crisp cut off of TV signal at the edge of coverage – reduces signal interference, ghosting, etc
7. Overseas systems are expected to be operational (Japanese, Australians, Europeans, etc.) about the same implementation time frame as the U.S.

Military users may be able to “rent” SDTV channels for GBS operations from commercial and PBS stations. The best use of that resource stateside would be to transmit data and information to local guard and reserve units.

HDTV Timeline

Current law and FCC rules allow for a phase-in of digital TV by the year 2006. At that time, broadcasters will have to give back their analog channels, due to be auctioned off by the FCC. During the process, TV stations will continue analog broadcasts. Eventually TV viewers are expected to buy a digital TV or a digital set-top box that adapts their current analog TV to display a low-resolution signal.

November 2, 1998: HDTV transmissions begin at 26 stations in the top 10 markets.

May 1999: Network affiliates in the top 10 markets, reaching 30% of TV viewers, must simulcast at least 50% of their analog programming on DTV.

November 1999: Network affiliates in the next 20 largest markets, representing 50% of all viewers, must offer DTV.

May 2002: Remaining commercial stations must convert.

2003: Non-commercial stations must convert.

2004: Stations must simulcast at least 75% of their analog programming on DTV.

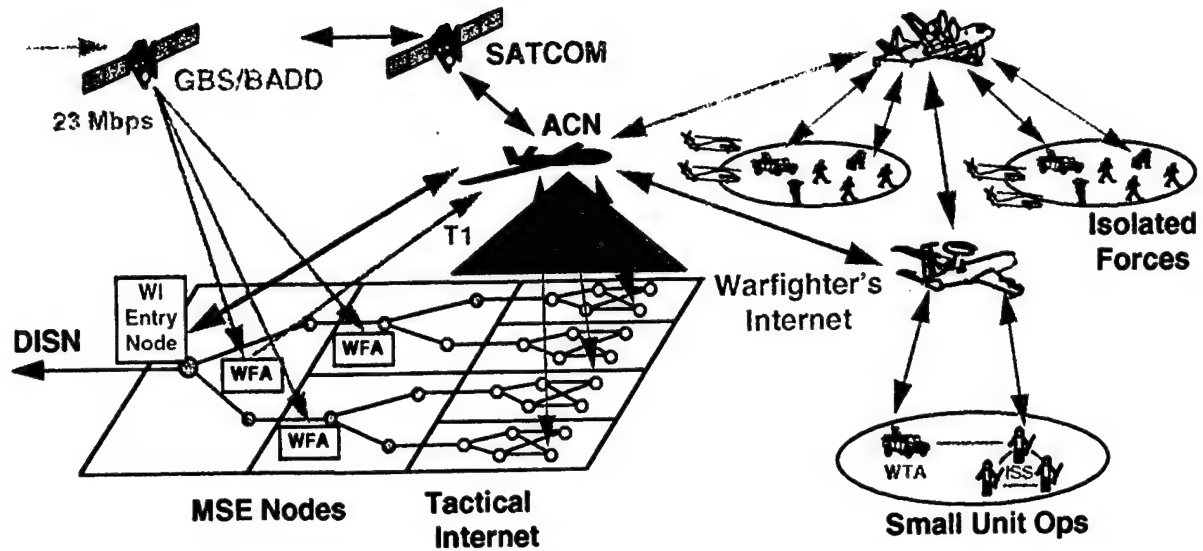
2005: Stations must simulcast 100% of their analog programming.

2006: Stations relinquish their current analog spectrum. Old NTSC receivers will no longer be able to pick up broadcast signals.

Fully available military support, digital communications operation, will be available in 2005. Digital radio development has not kept pace with its DTV counterpart. The timetable for digital radio implementation has not yet been defined.

The inclusion of digital television and the ACN will provide a more integrated information flow in the battlefield. See Figure 3. The highly mobile and complex nature of the new Warfighter's environment requires a rapid and seamless flow of information and communication across the battlefield from soldier to commander and return.

Figure 3 - Integrated information flow in the Battlefield¹⁸



Goals of Battlefield Communications

The goals for battlefield communications of the future include:

- Provide and validate new ideas in communication to support combat in the 21st century.
- Enable the seamless and robust distribution of voice, data, and imagery throughout the battlefield.
- Efficiently use precious resources such as radio bandwidth to support battlefield needs.

These goals set the tone for development and procurement. These goals are also the expression of the warfighters and the commanders and transcend into specific bottom line requirements.

Bottom Line Requirements

These goals though must translate into viable bottom line communication system requirements:

- Acquire information from sources and transmit it among databases and battlefield entities.
- Do this in a highly mobile military environment requiring low probability of intercept and jamming resistance.

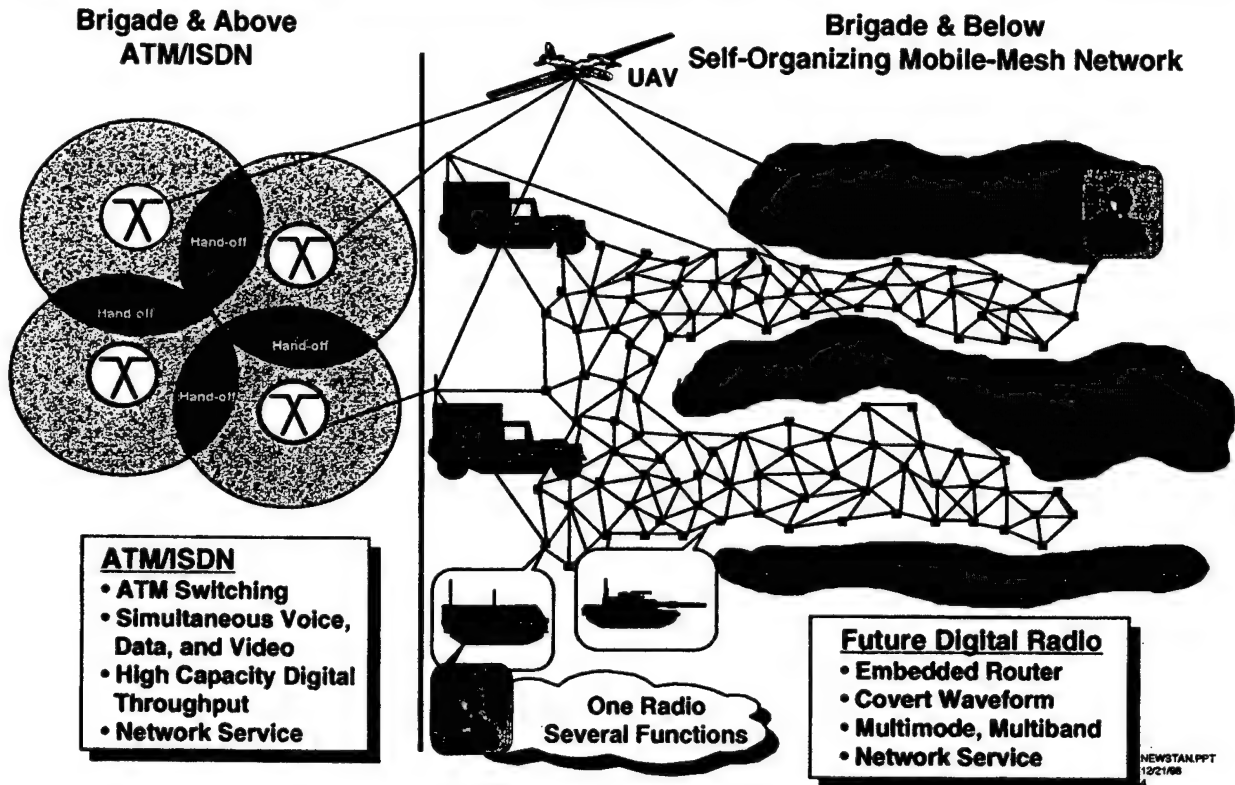
Mobile Wireless Communications

The new emerging battlefield is a complex and dynamic entity. It involves the application of newer force structures and operations in multiple scaled warfighting scenarios. The traditional large-scale operations have been supplanted by smaller more focused support roles. The US military has been and will continue to be called upon for world-wide support from many camps including the United Nations and NATO. The US has become the de facto world policeman, and its operations vary from small-scale rescue to larger scale Iraqi conflicts. The key in all of these newer operations is the application of communications, specifically mobile communications.

Figure 4, shown on the next page, depicts the vision for 2010 which is broken into two components the Brigade and above and the Brigade and below operations. The connectivity between the two must be seamless and timely. The connectivity is dependent upon newer technologies including the Future Digital Radio, the ACN, and ATM/ISDM.

Figure 4 - Mobile Wireless Communications – 2010 Vision¹⁹

Mobile Wireless Communications - 2010 Vision



Communications both commercial and military are dynamic in their development. What was once viewed as a long-term development and marketing process has made tremendous strides within the market place and the inclusion of newer technology. Computer based solutions have increased the capabilities of the individual system components as well as the system itself. An example of this is the fixed based cellular stations and the move to LEO based satellite systems. The following table describes the progression of communication capabilities as viewed by ARO:

Table 1 - Mobile Wireless Communications Capabilities (ARO – Dr. Freebersyser)

Characteristics	Present Civilian	Future Civilian	Future Military
Base Station Location	Fixed	Fixed	Mobile
Antenna Array	Base Station Only	Base and Mobile	All Nodes
Switching	Circuit	Packet (?) Uncertain	Packet
Routing	First/Last Wireless	First/Last Wireless	All Wireless
Message Priority	No	Quality of Service	Yes
Multicast	No	Yes (?) Uncertain	Yes
Network Control	Centralized	Distributed	Distributed/Self Organizing
Data Rate	10's of KBPS	100's of KBPS	Mbps
LPI/LPD and AJ	No	Yes (?) Uncertain	Yes
Spectrum Allocation	Commercial	Commercial	Military
Peer-to-Peer	No	No	Yes
Security	Growing Importance	Very Important	Very Important
Single Points of Failure	Yes	No (?) Uncertain	No
User Cooperation	No	No	Yes
Integrated GPS	No	Yes (?) Uncertain	Yes
Cost	Airtime	Airtime	Equipment
Depreciation (Life)	Yes (<6 years)	Yes (<6 years)	No (>20 years)

(?) Yet to be defined. It is an uncertain goal at the present.

How does this impact the military mission? As we look to the future and the evolving mission requirements, communications plays a more complex and central role. Table 2 addresses the traffic performance requirements as they apply to future missions for both Scouts and Forward Deployed Units. Other key areas of interest include area communication coverage and mobility.

Scouts and Forward Deployed units

Table 2 - Traffic Performance Requirements

Traffic Type	Speed of Service	Quality of Service
Voice	High; with low delay	Medium; low performance
Still Images	Moderate	High; low performance
SA data	High	Moderate
BC data	Moderate	Guaranteed Delivery

Assumes all voice transfers are packet voice and the subscriber terminal interfaces and/or functionality is to the current "Applique".

SA = Situational Awareness, BC = Bid Controller (Cellular and Internet Communications)

What are some the system requirements?

Area Communication Coverage

- Out to a maximum vertical range of 100 km

Mobility

- Dismounted soldier moves at 3 mph
- Vehicle mounted systems move approximately at 30 mph

Echelon to Echelons

Traffic Performance Requirements

Table 2 Performance plus the following:

- Transmit and receive real-time video point to point
- Half duplex broadcasting for conferences involving more than 2 people
- Support all users at a minim capability of 8 frames per second video/audio

Area Communications Coverage

- Same vertical range in Scout/Deployed Units
- 100 km deep by 50 km wide (echelon to echelon)

Mobility

- Same as Scout/Deployed Units

RAP/JMCOM

Traffic Performance Requirements

- RAPs (Radio Access Point) high bandwidth connection is ATM.
- RAP acts as concentrator node for multimedia and subscriber operations
- Composite cell error ate of less than 0.01% for all RAP links.

Area Coverage

- To be defined based upon inter service and inter organizational needs
- Base area is 50 km by 100 km

Mobility

- Movement at approximately 30 mph
- Communication rate not less than 1.5 Mbps²⁰

The communication and mobility requirements fall in line with the requirements that were developed under the FRI study

The Visions and the Plans – The Future

The battles of the future will embody the quick maneuver and versatility of Desert Storm with new and emerging communication technology. This merger will provide both the individual soldier and the battlefield commander with the ability to better visualize in real-time both the local and the total battlefield engagement process. Better decisions and more timely action will result. The force multiplier is technology.

“Joint Vision 2010 – the Joint Chief’s of Staff Vision for future warfighting – harnesses the power of information technology to enable the emerging operational concepts of dominant maneuver, precision engagement, focused logistics and full dimensional protection. Pivotal to this vision are the emerging concepts of information superiority and network-centric warfare – a global infrastructure of computing and communications.”²¹

“Plans call for the Army to field its first networked and digitized division, the 4th Infantry Division, by 2000. The III Corps at Fort Hood, Texas, is expected to be the first fully networked and digitized corps by 2004. As the road map to digitization takes shape, however, the challenges facing the Army in reaching this goal become more focused.

“These challenges include common problems ranging from designing a broad system architecture to solving the year 2000 computer bug. Bandwidth demands are increasing as public auctions render vital radio frequency spectrum scarcer. And, information security waxes in importance as the Army employs public networks in its overall system configuration.

“Two underlying key principles in the Army’s information system implementation philosophy and strategy are to support warfighter requirements and to employ mainstream commercial technologies.”²²

Communication Trends

Communication trends impact both the commercial arena and the military force structure. It includes multimedia services, digital TV and radio, high data rates, and communication and imaging satellite coverage improvements. In the military arena the warfighter is both the recipient of the trends and the advocate of them. Communication is the underpinning of an effective fighting force and the enabler for faster, more comprehensive decision-making. Satellite based systems are a major element of effective force wide communication.

“The Warfighter has a continuing requirement for satellite communications (SATCOM) systems to satisfy growing information transfer needs. SATCOM is often the primary communications means available to support US military operations in a global threat environment of regional conflicts that are unpredictable in location, time, duration, and intensity. While no two user communities have communications needs that are identical, there are common characteristics in their specific requirements -- interoperability, flexibility, global coverage, security, and assured access.”

“Access to SATCOM services is the most fundamental need of the warfighter. Deployed and mobile warfighters are largely dependent on SATCOM to satisfy their information transfer needs. Warfighters rely on SATCOM to maintain situational awareness, to exercise positive command and control, and to collect and disseminate intelligence, warning, and target acquisition information. Unified Combatant Commanders have repeatedly requested the ability to access SATCOM on demand and to control the resources apportioned to them by the Joint Chiefs of Staff. A Warfighter’s access to SATCOM support must be available on demand when and where needed for the duration on the mission. Such access allows the joint warfighter to collect and disseminate intelligence and orders rapidly. This

rapid transfer of information enables us to operate inside the enemy's decision cycle and retain the initiative."²³

"Current Department of Defense owned and operated satellite communications systems have finite lives. Within the next ten to fifteen years, the existing resources of the DoD SATCOM architecture will require replenishment. More importantly, the current systems do not possess the requisite capabilities to support the information demands of the future warfighting environment. The pressures of growing warfighter information requirements against degrading satellite transport systems have been recognized. Recent studies and analyses have begun the process to recommend and select a future architecture that balances warfighter communications needs against programmatic, funding, and technological constraints."²⁴

"No single space segment asset can satisfy all the needs of the warfighter. WIN and Force XXI will use a variety of space segment assets for communications. Each space segment and the frequency band offer advantages and disadvantages to the warfighter."²⁵

"A proper mix of military and commercial satellite systems are necessary to meet the requirements of a force projection Army. This mix will balance the capabilities and limitations of the various assets."²⁶

Global Broadcast Service (GBS)

"The Global Broadcast Service (GBS) is an evolving secure, integrated satellite broadcast service and information dissemination system based on commercial and high technology developments. GBS increases the capacity and velocity of information distribution. As a component of the WIN, GBS augments current space and terrestrial transport systems through one-way transmission directly to the Warfighter."

"GBS exploits commercial developments in the Direct-to-home Broadcast Service industry, i.e., DirecTV, DirectPC, PrimeStar. Direct-to-home Broadcast Service systems use compressed digital video technology and high-capacity satellite transponders to broadcast numerous channels of digital video, audio, and data to small inexpensive receivers. Because of their low cost, small size, and mobility, GBS will be fielded to tactical combat, combat support and combat service support units, at all command echelons, down to battalion level. The receiver terminals would consist of a small antenna system and a GBS receiver. GBS terminals would be capable of operating onboard aircraft, ships, and vehicles."

"GBS provides state of the art multimedia broadcast services to enhance warfighter C² capability. GBS provides a real time, continuous means to receive, access, retrieve, and archive battle command information. The information can come from national/strategic sources, or from tactical theater level. These information products can be video broadcasts, Unmanned Aerial Vehicle (UAV) video, Common Ground Station (CGS) sensor data, or other large volume data product. Some of the potential types of information available are:

- Movement control Information
- Air tasking orders
- Weather data
- Intelligence briefings/files
- MCS Blue Force data
- ASAS Red Force data
- UAV and satellite imagery
- News
- Theater ballistic missile defense warnings
- Logistics files
- Education/training material
- Intelligence briefings
- Commander's intent briefings
- Operations orders and overlays

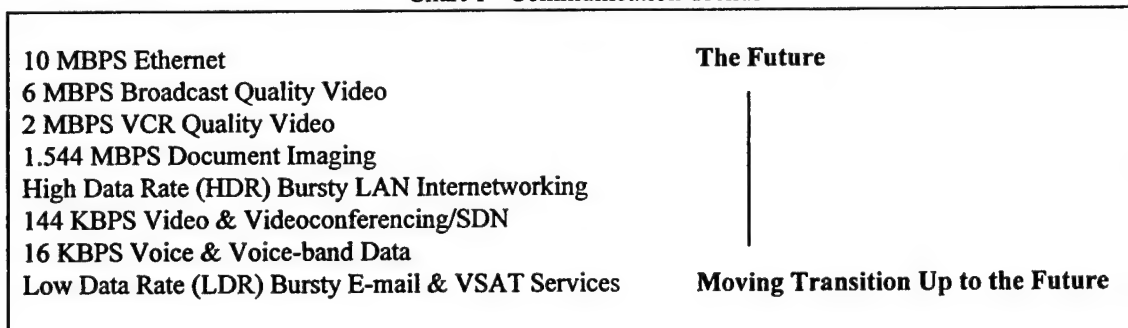
- Air tasking orders
- JSOI, telephone/E-mail directories
- Rules of engagement
- NBC status, warnings, and operational information
- Civil affairs and psychological operational information
- Software/Databases
- Morale/Welfare information
- Information from national sources and archives

"GBS provides a tailorable information dissemination system for the warfighter. At each echelon the user can define the type of information he needs and when he needs it. Users at GBS terminals (e.g. the current Warfighter Associate) will set profiles that define the time, area, and type of information they want to receive through the GBS system. They can also submit queries/requests for specific data. These profiles and queries are sent through the deployed communications architecture to the Information Dissemination Server (IDS), located in the continental United States."²⁷

Satellite links between WIN switches will be at data rates of 1.544 Mb/s to 4.608 Mb/s. CONUS links will be from 1.554 Mb/s up to 8 Mb/s depending the throughput requirements. Links to adjacent units (allied, etc.) will normally be smaller than 1.544 Mb/s.²⁸

The Communication Trends Chart 1 shows the movement/hierarchy of transmission rates and composition over time. "A brigade-level Tactical Operations Center (TOC) now has a peak load of 1.6 megabytes per second."²⁹ Today, we stand approximately in the middle of the trend as reflected in the TOC load requirements. Our goal is to implement the strategy and employ the technology to provide the 10 Mbps link capability. A combination of commercial technology, university research, and military research will provide the mechanisms and products to implement the strategy. The FRI is but one phase of that combined mechanism.

Chart 1 - Communication Trends



Components of a New Communications System

A new communications infrastructure has been emerging. It is one that includes

- a new family of communication satellites: IRIDIUM, GLOBSTAR, TELEDISIC, and ODYSSEY which are low-altitude, orbiting not geostationary systems;
- Cellular Phones capable of communicating without roam features, transferring calls from satellite to satellite and providing 4.5 KBPS Narrow-band Voice/Data; and
- Personal systems which provide 1.2 KBPS Messaging/Paging worldwide.

This is a very flexible infrastructure that transcends all national boundaries.

Architectural Concepts

“As the tempo of the battle and dependence on information increases, so will the demand for responsive data communications.”³⁰

“The fact that the warfighters must carry and operate equipment with them, operating at beyond line of sight operating communication ranges, “argues for a very different type of wireless data communications network than has ever been built, and one for which the technology that is needed is not yet available, either from commercial or military sources.”³¹

“The mobile warfighter cannot be given a dedicated or even a “dial up” (on demand) circuit; there will not be enough to go around.”³²

Communications Architecture

The architecture is composed of the WIN and the Warfighter Internet. Each of these supports the fabric of the future battlefield in unique ways. Each has its own characteristics and capabilities to support the soldier from the top down (flow down of information) or the bottom up (flow up).

WIN Architecture and Components

Communication and Information Service: Communications and information services will be key enablers for each element of the Force XXI pattern of operations: project, protect, and gain information dominance, shape the battlespace, decisive operations, sustain operations. Force XXI Doctrine must be flexible enough to enable forces to rapidly transition from one type of operation to another. Various operational experiences, warfighting experiments, advances in technology, and supporting concepts are sources which drive the process for developing Force XXI doctrine. They also provide focus for identifying critical warfighter requirements common to any potential operation undertaken in the information age. Some of these requirements include:

- a. C2 on the Move: The dynamics of future operations will require continuous mission analysis and potential changes to plans. As a result, battle commanders require reliable C2 capabilities in garrison locations and during the deployment phase while enroute to the theater of operations. They also require the ability to exercise C2 from anywhere within the battlespace.
- b. Mobile and Flexible Command Posts: The ability to rapidly pick-up and move a Command Post (CP) to keep pace with operations is essential. Satellite, wireless LANs and Personnel Communications Services (PCS) will enhance CP mobility.
- c. Situational Awareness: The force must have accurate, real-time knowledge of friendly, enemy, neutral, and noncombatant activities and locations.
- d. Reliable, Robust, and Survivable Information Systems Supporting Force Projection and Split Based Operations: Seamless connectivity from sustaining base to the foxhole is the rule for future signal support to warfighting forces. Multiple, non-interoperable, "stovepipe" communications systems existing today are too resource intensive and do not fulfill this requirement. Users must have the ability to "unplug" from the network in the sustaining base, and "plug-in" wherever they deploy without being concerned with the issues of connectivity, compatibility, interoperability, ease of service, etc.
- e. Security/C2 Protect: Information protection measures must be easily implemented and reliable to ensure information dominance.
- f. These and other warfighter requirements form the foundation upon which the WIN concept is built.

Warfighter Information Network (WIN)

WIN, is an evolving integrated C⁴ network that is comprised of commercially based, high technology information and communications systems. WIN is designed to increase the security, capacity, and velocity of information distribution throughout the battlespace in order to gain information dominance. WIN will maximize secure information services for the Warfighter and support the power projection force of the 21st century from sustaining base to foxhole.³³

Another component of the architecture is the Warfighter Internet.

Warfighter Internet

Information on the Warfighter Internet is available on page 12.

Airborne Communication Node (ACN) – An Enabler

The ACN is a technology enabler. It both extends communication range and functionality.

“Airborne assets can be used to extend communications capabilities. The airborne nodes considered for the battlefield include the ACNs on Global Hawk flying at 65,000 ft. These nodes provide capability for the Warfighter’s Internet.”³⁴

Airborne Communications Node

a. The Airborne Communications Node (ACN) combines the capability of a high-altitude endurance UAV with the essential capabilities of a state-of-the-art communications package (node). The ACN’s capability to self-deploy anywhere in the world will free up airlift assets that can be used for other missions. The ACN will carry robust communications packages that can be reconfigured rapidly to support changing C² priorities. High gain antennas coupled with the ACN’s ability to loiter at very high altitudes (65,000 feet and higher) for extended periods of time will enable tactical users equipped with lightweight omnidirectional antennas and low powered radios to establish over-the-horizon communications from mobile platforms. This capability will provide a significant improvement in C² on the move (C²OTM).

b. The ACN will be a uniquely capable platform for greatly improving battle command and battle management communications. The ACNs lift capacity will allow it to carry a large, multi-band, multi-mode, and robust communications payload to support a relatively large number of subscribers. Some of the possible communications payloads are:

- Tactical Command, Control, and Communications (C³)
- Theater Missile Defense (TMD)
- Infrared Radar (IR) sensors
- Synthetic Aperture Radar (SAR)
- Communication Control Element (CCE)
- MSE Range Extension Radio (MSE RER)
- Global Broadcast System with Common Data Link (CDL) capability
- Electro-Optical (EO) sensors
- Multifunctional Information Distribution System (MIDS)

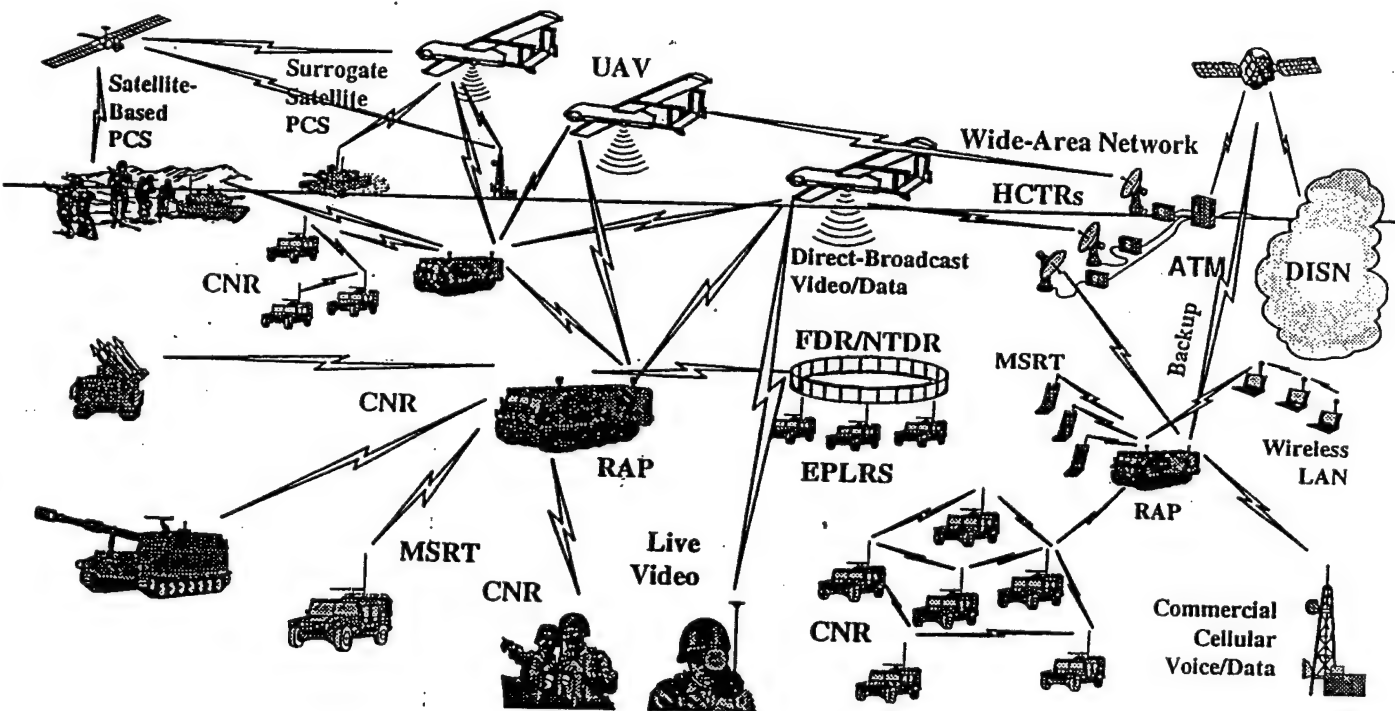
As an essential part of WIN, the ACN contributes to the rapid connectivity of the entire network. The force projection capabilities of the ACN will greatly enhance the communications capabilities of the WIN architecture. The ACN will provide reach-back connectivity from the area of operations to sustaining bases. It will also provide gateways for seamless communications between dissimilar communications systems. The ACN will provide communications redundancy to ensure Force XXI information dominance,

reduce the requirement for terrestrial line-of-sight radio relays, and provide new types of communications services directly to the warfighter.

Although the ACN augments commercial and military satellites, it does not replace them. Satellites and satellite radio systems operate in specific frequency bands and provide unique communications services to support WIN. Satellites, however, will not have the capability to support range extension for every type of military radio and communications system. Range extension for voice and data line of sight communications through the ACN will enhance the Warfighter's C² capability.³⁵

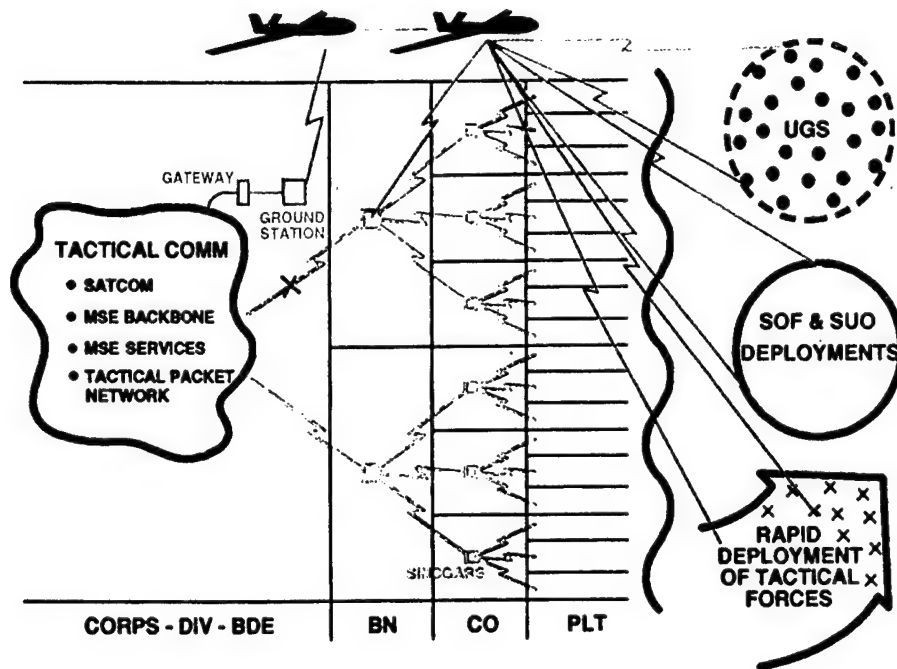
Figure 5 provides a view of the Future Digital Battlefield with all of its components.

Figure 5 - The Future Digital Battlefield



The Warfighter's Internet fits well into the existing tactical communications structure. It can provide an alternate or primary backbone to battlefield communications both stationary and on the move. It can complement the vast array of services both available and needed on the battlefield. It can extend the ability to individualize communication.

Figure 6 - Warfighter's Internet as an Overlay to Existing Tactical Communications
(Reference: "Architecture and Concept of Operations for a Warfighters Internet", p. 1-4)



Summary

The battlefield and its nuances are dynamic not static and the communications needs follow similarly. The components of the new digital battlefield include cellular telephone, asynchronous transfer mode (ATM), ISDN, the Internet, digital television, the Airborne Communication Node (ACN), communications satellites (LEO, MEO and GEO), the Future Digital Radio (FDR), and the Joint Tactical Radio (JTR). These are the technologies along with spread spectrum, frequency hopping, burst transmissions, TDMA, FDMA and DAMA signal transmission capabilities.

The conditions on the modern battlefield along with the capabilities of potential enemies dictate that the US develop and field systems that are survivable and extremely capable. As we realize these conditions and requirements, our research efforts much support and lead the development of capabilities and resulting equipment.

The utility of our research efforts must more than justify the expense. Research must lead to concrete results and fieldable equipment to sustain our warfighters whether on land, in the air, on or under the seas, or in space, our latest frontier. The next section addresses the concept and application of Research Utility.

Research Utility

Digital battlefield description and expected role

The future digital battlefield has been described previously. The communication performance standards and expectations show the expanding importance of the immediacy and quality of communication service to the Warfighter. Smaller units, greater firepower, the tempo of the battle, and mobility on the battlefield dictate that the communication of information and visual data is of paramount importance and urgency. Time management is the essence of the new battlefield. Along with these needs exist the need for compact and lightweight transportable systems, the need for accuracy, and the need for dependability. Information is the force multiplier today and into the future.

Requirements & Goals

Unit and/or organization based

The organizational relationship between military units is changing. Unit responsibilities are becoming increasingly more complex with the emergence of new weapon systems and the control of larger territorial zones. Communication is the glue and underpinning of the new highly mobile unit.

"The US Army's first digitized division in 2000 will control an area 600 times larger than the conventional division of 1984, thanks to enhanced digital communications capabilities. The typical Army division of 1984 controlled a battlefield of nearly 25 square miles. But new communications systems will enable the first digitized division, the 4th Mechanized Infantry based at Fort Carson, Colorado, to control an area of 14,880 square miles, says Maj. Gen. Gerad Brohm, who leads the Army Communications-Electronics Command (CECOM) at Fort Monmouth, NJ."³⁶

Challenges

With new responsibilities comes the need for a new communications infrastructure or network. "Leaders of all the US Military services are seeking to increase their ability to communicate between deployed forces – using what they know increasingly as "network centric" systems. Yet, US Army commanders are struggling to meet the growing communications bandwidth and security requirements that experts say will be necessary for them to wage warfare effectively in the 21st century."

"In future warfare, Army tacticians envision many small units operating over broad stretches of the battlefield. Yet to do this effectively without being overwhelmed by the enemy, Army planners face a command and control problem that involves the need for an ever-greater two-way flow of information in areas where wireless communications are vulnerable to interception and jamming."

"Each new increase in battlefield connectivity proportionally increases the vulnerability of communications networks."³⁷

To summarize some of the challenges that the Army will face, they include:

1. Throughput of data and voice
2. Terrain blockage
3. Connectivity within units
4. Soldier's ability to discern the immediate battlefield
5. Implementation and operation of cellular on the battlefield
6. Available number of IP addresses for tactical Internet operation
7. Defining big picture and where it is located

8. Managing the wealth of data and information on the battlefield
 - a. Data fusion
 - b. Data reduction
 - c. AFATDS System and others - information loads

Based upon the eight challenges described above, what is the full range of communication needs?

Range of Communication Needs

Discussion

Table 3 - Army Tactical Communication Needs³⁸

Element	Commanded by	Typical Number of People	Map Symbol	Approximate Geographic Area F x D Coverage
Corps	LTG	200,000 3-5 Divisions	XXX	250km x 150km (37,500 sq. km)
Division	MG	10,000-15,000	XX	50km x 75 km (3,750 sq. km)
Brigade	COL	5,000	X	15km x 10km (150 sq. km)
Battalion	LTC	800	II	
Company	CPT	200	I	
Platoon	LT	40		
Squad	SGT	10		

Military Challenges

“The Army’s primary focus on communication arises out of the operational need to command, coordinate, and control highly mobile units on the battlefield.”³⁹ The challenges are a direct result of that operational need. The major communication challenges are defined as:

- a. Communication on the move
- b. Mobile warfare produces highly dynamic network topography
- c. Spectrum allocation and bandwidth efficiency

The Army’s tactical communications system for the Digitized Force XXI battlefield has evolved as a combination of systems:

1. At the upper echelon, a circuit switched transportable backbone system (Mobile Subscriber Equipment, MSE) is employed. It is capable of handling large amounts of traffic and is evolving into a wide area ATM system in order to support future multimedia applications.
2. At the lower echelon (Brigade and below), a highly mobile IP-based network (the Tactical Internet TI) is employed that handles data and needs to time-share data access with voice. This lower echelon system is currently voice traffic dominated and is expected to remain so for a significant time into the future.
3. To enhance the connection between the highly-mobile tactical Internet and the transportable MSE, a tracked vehicle, the Radio Access Point (RAP) may serve as a concentrator node interfacing to the TI,

and (through a High Capacity Trunk Radio, HCTR) to an MSE extension node. If this link is Beyond Line of Sight (BLOS), then the airborne node carrying the Warfighter Internet could also relay this RAP traffic.⁴⁰

Table 4 Total Subscriber Population⁴¹

Area	Subscribers	Total Subscribers
Corps/Division Rear	8000 voice 1900 Mobile Voice 2000 IP Data	11,900
Brigade	1000 voice + IP Data All Mobile	20,000
		31,900 Total Subscribers

"The warfighter and platforms that carry these systems constitute a mobile force that must move rapidly on the battlefield (foot soldier at 3 mph up to vehicles at 60 mph and helicopters at 300 mph). Units can leapfrog one another, move more than once a day, and therefore cannot use fixed tower or fixed network resources, but instead must create their own supporting mobile communications infrastructure. The ability to rapidly create such a mobile infrastructure is a key difference between military and commercial communication systems and the technology required to implement them."⁴²

"The WI shares the same high mobility requirements with the lower echelons of the Army Communications infrastructure, but does not, by itself, have to handle the total magnitude of traffic or support all of the theater user population described above. But rather is complementary to the standard communications systems (MSE, TI), since it is used to provide connectivity to that smaller fraction of the force that cannot be covered by standard systems. The Army's continued need for real time voice, multimedia, and large file transfer of data in very large volume, particularly at higher echelons, raises serious questions about capacity of the theater network needed to support all of these services. The WI has assumed its primary traffic will be data from a limited set of users to maintain seamless communications. There will be battlefield scenarios and services where WI alone can, indeed, satisfy these user needs, but for larger deployments and at higher echelons, standard Army communications systems are essential."⁴³

Eight Classes of Data Service

"Eight classes of data service have been identified for situations that involve the following: a limited number of communication subscribers, rapid motion, possible separation from a main force, and the need to eventually transition into the primary communication systems capable of supporting user traffic needs."⁴⁴

The classes from the DARPA study are outlined as follows⁴⁵ :

1. Administrative/Logistics: mostly a flow up of traffic, with each command level summing information from below before transmitting further; therefore, messages all essentially the same length regardless of level; currently voice or hand delivered.
2. Intelligence (non organic sources): largely imagery and textual interpretation flowing into Brigade S2 from higher echelons; only text likely to be propagated below brigade; flow down limited to affected (and adjacent) units; currently hand delivered.
3. Intelligence (organic to the Brigade): fundamentally a flow-up on a message-by-message basis; includes Contact, Obstacle, Spot, etc., Reports; currently voice; *augmentation by video from FLOT useful in the future.*
4. Combat Planning: Conference sessions for 15 minutes to 3 hours each; currently largely face-to-face meetings with no relevant data transmissions: *Multimedia capability desired in the future.*

5. Dissemination of Orders, including Tactical Overlays: basically a flow-down limited to affected (and adjacent) units; currently hand delivered.
6. Friendly Situation Awareness: currently very limited position information, passed by voice; near-future data will flow up from each individual platform and then a union of all (friendly) platforms' positions, etc., will flow down.
7. Enemy Situation reports: A real-time distribution of fused information, which is basically updating the Enemy Overlays (see No. 5 above). The reports are generally a flow down from Brigade and Battalion S2s to affected (and adjacent) units. It is currently provided by voice.
8. Coordination: Exchanges between adjacent elements and/or combat branches for mutual support (artillery, MEDEVAC, etc.); logical flow mostly between involved units, hence traffic amounts related to level, not numbers of platforms.

Our FRI research is addressing the enabling technologies and methodologies to solve the challenges and to support the eight classes of data service.

**Requirements Documentation
For
Focused Research Initiative**

The army is not the only military agency concerned with implementing services and capabilities supported by communication digitization. The following are other requirement documentation that supports battlefield communications needs. These requirements are from Air Force sources but are directly applicable to the army digital battlefield. These are specific ORD and MNS requirements in the digital communication and information battlefield area. The reference numbers identify the source agency and whether this is an ORD or MNS. A list of deficiencies, that the ORD or MNS addresses, is found at the end of each individual ORD or MNS segment. A summary comparison matrix of the listed ORD and MNS against the overall FRI requirements listing is provided on page 47.

Reference Number.....: **AIA MNS 003-95**

Document Name.....: **Operational Defensive Counter-information Warfare Capability, Mission
Need Statement (U)**

System Capability/Characteristic: **Protect C4I Systems**

Organization.....: **AFIWC/EA**

Specific Mission.....: **Information Operations**

Requirements Text:

The Air Force currently can, at best, only marginally predict, deter, detect, intercept, isolate, contain, and recover from disruption or hostile exploitation of advanced technology-dependent, information-based weapon and C4I systems. The USAF is critically dependent upon advanced weapon and C4I systems throughout all mission areas. USAF weapon and C4I systems are a friendly Center of Gravity that an opponent could currently effectively attack with minimum effort and little-to-no risk at minimal cost. Such an attack could inflict extreme damage to the ability of the USAF to remain an effective combat force. Air Force DCI capabilities presently range from limited to nonexistent. Specific deficiencies are:

- (1) Limited USAF structure exists to integrate and control DCI operations. Likewise, there is limited USAF ability to conduct DCI activities. The USAF is presently unable to coordinate or conduct a common defense of C4I systems. The USAF lacks systems to develop effective threat information and countermeasures and coordinate defensive measures against attacks regardless of whether they are made by wire, fiber optics, free space or any other means.
- (2) Technological resources do not exist to perform a DCI function simultaneously in both unclassified and classified environments, and in electromagnetic, wire, and fiber-optic communications media.
- (3) Currently, no capability to exercise DCI resources exists in an operational environment. Without such capability, the USAF cannot predict, deter, detect, intercept, isolate, contain and recover from disruption or hostile exploitation of advanced technology-dependent information-based C4I systems. This lack of capability jeopardizes the survival of United States and allied forces and the successful execution of military operations. In addition, current resources are not adequate for the levels of field support required to correct DCI deficiencies USAF wide.
- (4) Limited personnel and equipment exist for wartime, exercise and readiness support to field units. They will not fully assess existing and newly developed USAF weapon and C4I systems, gather information from the field, respond to security incidents, and provide viable security countermeasures. Further, they will not completely address the demand for evaluated computer products and embedded COMSEC applications; determine C4I systems' electromagnetic vulnerabilities; identify and define existing DCI vulnerabilities; and furnish DCI advisory, warning, and response services to the USAF.

Constraints:

a. Logistics.

Any new systems must be highly reliable, maintainable and logistically supportable. Interoperability, maintainability, and reliability capabilities such as built-in-test should be included in system design to facilitate maintenance and minimize logistics support costs.

b. Transportation.

Deployable capabilities should be transportable worldwide and scaleable/modular to meet national security objectives for regional crisis.

c. Mapping, Charting, and Geodesy.

Not Applicable.

d. Manpower, Personnel, and Training.

The user will determine operations, maintenance and logistics support manning required, with the goal of minimal increase in manpower requirements for the Air Force. Current resources have been adequate to define and initiate the required programs to support only 2,500 computer systems. Personnel and equipment are required for wartime and readiness support to field units. They will assess existing and newly developed USAF computer systems, gather information from the field, respond to security incidents and provide viable security countermeasures. Further, they will address the demand for evaluated computer products and embedded COMSEC applications; determine C4I systems' electromagnetic vulnerabilities; identify and define existing DCI vulnerabilities and furnish DCI advisory, warning and response services to the USAF. Support teams require connectivity to Defense Secure Networks, MILNET, modem pools, commercial telephone lines, major networks and theater C4I systems. They will collaborate with other services and national laboratories to assess vulnerabilities, develop and test new countermeasures and provide responsive deployable support to USAF units.

e. C4I Interfaces.

DCI technology developed will require support from intelligence data handling systems, databases and analytical applications. Deployed systems will interface with existing and future mission planning systems. At a minimum, interfaces should not degrade the performance or survivability characteristics of any interfacing or interfaced systems. Implementation of limited access (i.e., firewall, guard, filter) and related technologies are needed to allow unclassified USAF systems to access national and international networks as necessary, while inhibiting unauthorized access to USAF systems.

f. Intelligence.

Intelligence support is required to develop and maintain databases and to predict and track the structured threat to C4I systems to effectively protect those systems.

g. Security.

The information protection effort will involve access to information classified up through TS/Codeword. The output of the DCI technologies and the information flowing across transmission paths should, in practice, be kept to a Secret/Collateral level or lower. Security must adhere to the standards and guidelines to assure proper protection of communications, computer and information systems. Program protection will be applied throughout the system's lifecycle to maintain technical superiority, system integrity and availability. System security measures must be applied to integrate facilities, procedures and equipment. Embedded C4I systems must be designed to counter the threat vulnerabilities identified in the 15 Jan 94 threat environment description on C4I Systems.

(1) Communications Security (COMSEC).

COMSEC will be maintained through the use of available secure networks. COMSEC procedures as outlined in the applicable standards and regulations will be followed to the maximum extent possible.

(2) Computer Security (COMPUSEC).

Protection of computer resources will be IAW prescribed regulations. Risk analysis and operating approvals must be predefined for both operational systems and support facilities to ensure compliance in-garrison and to facilitate future determination at any deployed location.

(3) Physical Security.

Components must meet the requirements established for the highest classification of data accessible IAW applicable standards and regulations. Specific security measures are determined by a number of factors,

including service location, and suspected threats and vulnerabilities. The Designated Approval Authority (DAA) will perform the risk assessment, specific security measures, and operating approval for service operation.

(4) Protection of Classified Information.

All classified information, documents, electronic transmissions, and hardware shall be given appropriate levels of protection as required by DoD regulations and instructions.

DEFICIENCY: IO

NUMBER: **IFAP-96-01**

NAME: Lack of Effective Hardware/Software Processes and Procedures to Protect C4I Systems from Hostile Electronic Exploitation and Disruption (U)

DEFICIENCY: IO

NUMBER: **IFAP-96-02**

NAME: Lack of Capability to Predict, Deter, Intercept, Isolate/Contain, and Recover from Information Attacks against Secure and Non-Secure C4I Systems. (U)

DEFICIENCY: IO

NUMBER: **IFAP-96-03**

NAME: Lack Capability to Fully Test/Exercise the Ability of C4I Systems to Detect Intrusion Attempts, Implement Countermeasures or Report Intrusions (U)

DEFICIENCY: IO

NUMBER: **IFAP-96-06**

NAME: Lack of communications link/capabilities and IW/C2W applications to process and disseminate critical information to combat commanders quickly and in usable format (U)

Reference Number.....: **JORD 301-95**

Document Name.....: Joint CAF-USA, USMC, USN Operational Requirements Document (ORD)
301-95-CAPSTONE for the Common Imagery Ground Surface Station
(CIGSS) (U)

System Capability/Characteristic: Electronically receive, transmit, and disseminate high-quality imagery
intelligence (IMINT) products

Organization.....: ACC/DRR

Specific Mission.....: Dissemination

Requirements Text:

The network of CIGSS compliant ground and afloat systems will provide Unified, Joint Task Force (JTF), and component commanders with near-real-time (NRT) unexploited imagery, and provide the means to electronically receive, transmit, and disseminate high-quality imagery intelligence (IMINT) products. IMINT is vital to satisfy the battlefield commanders' need for detailed NRT information on enemy forces to efficiently allocate friendly forces, provide targeting information, provide mission planning information, and assist in the critical decision making process. During peacetime, crisis/contingency, and war, imagery is used for battlefield management, indications and warning, enemy force monitoring, terrain analysis, and battle damage assessment (BDA). Modern precision weapons employment has significantly increased the Warfighter's need for NRT detailed imagery. Also, the modern rapid pace of movement and dynamic change on the battlefield requires imagery to be delivered quickly to assist and support the decision making and force execution process. Operations directly supported by CIGSS compliant systems include, but are not limited to, deep surveillance, target acquisition, interdiction, special operations, noncombatant evacuation operations (NEO), humanitarian relief, peacekeeping operations, and base defense.

Reference Number.....: **CONOPS for CIGSS**
Document Name.....: **Interoperability Among Common Imagery Ground/Surface Systems**
(CIGSS), Concept Of Operations (CONOPS) (U)
System Capability/Characteristic: **Near Real-Time Imagery**
Organization.....: **DARO**
Specific Mission.....: **Dissemination**
Requirements Text:

The mission of CIGSS is to respond to joint and/or component operational requirements in the receipt and exploitation of national, theater, and tactical imagery. The CIGSS is a project that aggregates all of the current DARP imagery ground/surface systems into a single Defense Airborne Reconnaissance Office (DARO) project; it is the vehicle for migrating to a Common Joint Service Imagery baseline. The objective is to enable all CIGSS-compliant systems to be able to receive, process, exploit, and report any imagery source regardless of platform or imagery sensor type using common standards for graphic reports, graphics, reports, and Secondary Imagery Dissemination Systems (SIDs). The CIGSS project migrates imagery ground/surface systems to an open system architecture employing networks with standard interfaces for all components and functions. It maximizes the use of commercial-off-the-shelf (COTS) and government-developed equipment and software to provide the Joint Task Force Commanders with an integrated and interoperable airborne reconnaissance imagery processing and exploitation capability which can be tailored for all levels of conflict.

Reference Number.....: CAF(USAF) 007-89
Document Name.....: Tactical Secure Data Communications, CAF (USAF) 007-89-I/II/III-A, ACC
Operational Requirements Document (U)
System Capability/Characteristic: Secure Communications
Organization.....: ACC/DRCG
Specific Mission.....: C3
Requirements Text:

This ORD satisfies HQ USAF SON 007-89, which identified the need to efficiently use available transmission media in and between fixed operating and forward/deployed locations to transfer time-sensitive command and control, intelligence, and other mission support digital data. This information transfer will occur within the command chains, both vertically and horizontally, within the air control system (ACS), the numbered air force wing/squadron structure, and in the joint/combined structure. Execution of air operations is increasingly complex and becoming more dependent upon automation. The ability to rapidly identify threats and targets, allocate resources, disseminate intelligence, plan mission execution, etc, has increased the demands upon finite communications resources. Deployable command, control, communications, and intelligence (C3I) systems must be able to rapidly, reliably, and securely move this mission critical information to ensure effective application of air power. Therefore, efficiency of available data transmission media must be maximized to satisfy digital data transfer requirements.

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-27

NAME: Insufficient Data Link Connectivity and Capacity (U)

DEFICIENCY: INTEL

NUMBER: S&R-96-49

NAME: Inability to Quickly Transfer Mission Database to Relief Platform (U)

DEFICIENCY: IO

NUMBER: TBM-96-03

NAME: TBM systems unable to pass secure/anti-jam data/voice via common means in a timely manner (U)

DEFICIENCY: IO

NUMBER: TBM-96-09

NAME: Air Force & MAJCOMs Unable to Perform Deliberate and Crisis Action Planning and Execution Capability. (U)

DEFICIENCY: IO

NUMBER: TBM-96-66

NAME: Split ASOC Operations Strain Current Communications Capability (U)

DEFICIENCY: INTEL

NUMBER: CBO-96-SP06

NAME: Limited Joint Tactical Communications Interoperability (U)

DEFICIENCY: INTEL

NUMBER: CBO-96-SP08

NAME: Current Tactical Communications inefficient to operate (U)

DEFICIENCY: INTEL

NUMBER: S&R-96-CM027

NAME: Need for assured receipt of timely/accurate data supporting mission planning and execution (U)

DEFICIENCY: INTEL

NUMBER: S&R-96-CM003

NAME: Data Flow, Data Rates Inadequate to support air campaign operations (U)

DEFICIENCY: INTEL

NUMBER: S&R-96-CM022

NAME: Lack of large capacity digital links (U)

Reference Number.....: CAF 315-92
Document Name.....: Real-Time Information in the Cockpit, Final MNS (U)
System Capability/Characteristic: Real-Time Information to the Cockpit (U)
Organization.....: ACC
Specific Mission.....: RTIC
Requirements Text:

MNS CAF 315-92 Real-Time Information in the Cockpit (RTIC). There exists a need to provide airborne aircrews timely and essential off-board information to allow mission adjustments in response to a rapidly evolving combat environment. The RTIC concept envisions the capability to transmit accurate, timely and consistent mission essential information to airborne aircraft, thereby augmenting the aircraft's onboard sensors. The information must be presented in the cockpit in a "user-friendly" manner and format commensurate with aircrew workload. The objectives of the RTIC concept are to achieve a technological advantage to better employ a reduced force structure, while serving as a force enhancer. STATUS: COMACC Validated 24 Mar 94; CSAF Approved 26 Apr 94.

DEFICIENCY: OTHER

NUMBER: CA-96-32

NAME: Weapon Support (S)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-22

NAME: Lack of Real-Time Threat/Situation Awareness Information to In-Flight Surveillance and Reconnaissance Aircraft (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-27

NAME: Insufficient Data Link Connectivity and Capacity (U)

DEFICIENCY: IO

NUMBER: TMD-96-04

NAME: Timely Dissemination of Target Data to Warfighter (TM-04) (U)

DEFICIENCY: IO

NUMBER: CA-96-29

NAME: Avionics Displays/Processors (U)

DEFICIENCY: INTEL/IO/SIGINT

NUMBER: S&R-96-01

NAME: Insufficient collection and processing assets (U)

DEFICIENCY: IO

NUMBER: TBM-96-37

NAME: HVAAs Unable to Receive Near Real Time Intelligence While Airborne (U)

DEFICIENCY: IO

NUMBER: TBM-96-11

NAME: AETACS Unable to Receive ATO/ACO Once Airborne (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-CP076

NAME: Automated Onboard Correlation of Offboard Data (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-CP078

NAME: Airborne and cueing of other S&R assets.(U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-CP102

NAME: Lack of Fused, Unambiguous, Near-Real Time Combat Identification/Situation Awareness (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-CP105

NAME: Insufficient Off-Board Data Integration on the RC-135 (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: S&R-96-CP125
NAME: Poor sensor cross-cueing, correlation (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: S&R-96-SV01
NAME: Fielded "real-time information in the cockpit" (RTIC) tools (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: S&R-96-SV02
NAME: Lack of AOR enroute threat warning support (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: S&R-96-SV09
NAME: Real-time SEAD Cueing (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: S&R-96-SV13
NAME: Need threat warning for enroute to AOR (U)

DEFICIENCY: INTEL
NUMBER: S&R-96-CM012
NAME: RTIC Dissemination Network (U)

DEFICIENCY: INTEL
NUMBER: S&R-96-CM016
NAME: Joint STARS - MTI-SAR to Shooter (U)

DEFICIENCY: INTEL
NUMBER: SID-96-29
NAME: Inadequate threat warning for aircraft enroute to AOR (U)

DEFICIENCY: INTEL/SIGINT
NUMBER: IMSP-98-PD24
NAME: Lack of fielded real-time information in the cockpit (RTIC) tools (U)

Reference Number.....: CAF 311-92-I-B
Document Name.....: Theater Deployable Communications, CAF-AMC-AFSOC 311-92-I-B,
Operational Requirements Document (U)
System Capability/Characteristic: Deployable Communications
Organization.....: ACC/DRCG
Specific Mission.....: C3
Requirements Text:

This ORD satisfies CAF-AMC-AFSOC MNS 311-92 which identified a need for deployable communications systems capable of supporting command, control, intelligence, weather, logistics, and other mission support functions from initial deployment through sustainment. In joint and combined operations, the joint task force (JTF) commander must have access to status of subordinate forces from all services. The objective is to achieve interoperability between deployed Air Force elements, the JTF commander, other services, allies, and CONUS/theater command and control centers. We must provide the warfighters a reachback to centralized C2 facilities including communications between deployed systems and CONUS and/or established overseas theaters. This reachback must provide immediate access to and from the forward location. Finally, the AF must evolve to non-developmental item (NDI) communications systems that are interoperable with joint service systems to meet the objectives of the Joint Staffs Command, Control, Communications, Computers, and Intelligence (C4I) for the Warrior.

DEFICIENCY: INTEL

NUMBER: TBM-96-01

NAME: AOR TBM forces have increasingly limited ability to communicate within AOR or outside
AOR (for reachback) (U)

DEFICIENCY: INTEL

NUMBER: TBM-96-64

NAME: ADS unable to provide CADS data to CTAPS (U)

Reference Number.....: **CAF306-94-I/II/III-A**
Document Name.....: **Tactical Information Broadcast Service (TIBS), CAF 306-94-I/II/III-A,**
Operational Requirements Document (U)
System Capability/Characteristic: **Information Dissemination**
Organization.....: **ACC/DRFS**
Specific Mission.....: **C3**
Requirements Text:

The requirements in this ORD respond to the major program planning objectives of the Defense Planning Guidance (DPG) for FY95-99, 28 Sep 93, and emphasize priority improvements for joint and combined communications interoperability in all mission areas to facilitate joint and combined task force operations. These interoperability advances will pursue technological superiority and place high priority on Science and Technology (S&T) to help mitigate the effects of force reductions. The TIBS supports joint integrated connectivity worldwide with reconnaissance information derived from space and terrestrial sources to deliver usable near-real time intelligence information to theater and tactical forces.

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-27

NAME: Insufficient Data Link Connectivity and Capacity (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: S&R-96-28

NAME: Lack of Multi-Platform Data Link Interoperability and Commonality (U)

Reference Number.....: USAF 004-91
Document Name.....: Theater Missile Defense, CAF MNS (U)
System Capability/Characteristic: Theater Missile Defense
Organization.....:
Specific Mission.....: S&R
Requirements Text:

The four elements of TMD are attack operations (counterforce), active defense, passive defense, and command, control, communications, and intelligence (C3I). TMD will be conducted through established AF missions (counterair, interdiction, and force enhancements). AF roles and missions make it the more appropriate proponent for theater missile (TM) prelaunch, launch, and boost phase detection/destruction. Army roles and missions make it the more appropriate proponent for point defense in the terminal phase. Existing command relationships of tactical air defense extend into TMD; however, the constrained decision cycle for addressing TM threats requires closer integration of space components with theater components. The Joint Force Commander has overall mission responsibility. The Joint Force Air Component Commander (JFACC) performs as theater area air defense commander/airspace control authority, integrating surface-to-air missiles (SAM), bomber, and fighter assets. The JFACC plans interdiction and counter-air operations in accordance with the Joint Force Commander's priorities.

DEFICIENCY: IO

NUMBER: TMD-96-04

NAME: Timely Dissemination of Target Data to Warfighter (TM-04) (U)

DEFICIENCY: IO

NUMBER: TMD-96-09

NAME: No Dynamic Interactive Automated Ability to Understand an Adversary TM Operation (TM-09) (U)

DEFICIENCY: INTEL

NUMBER: TMD-96-02

NAME: Limited TMD Data Link Interoperability (U)

DEFICIENCY: INTEL

NUMBER: TMD-96-03

NAME: Lack Beyond Line-of-Sight (LOS) JTIDS inter/intra-theater (TM-03) (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: TMD-96-11

NAME: Limited Capacity to Detect, Track, and Identify Cruise Missiles/UAVs by both surveillance and attack aircraft (U)

DEFICIENCY: INTEL/SIGINT

NUMBER: TMD-96-12

NAME: Inadequate Track-to-Track Correlation Algorithms (TM-12) (U)

DEFICIENCY: INTEL

NUMBER: TMD-96-08

NAME: NRT Characterization (Warhead Typing)--Pre and Post Launch (TM-08) (U)

General Outline of the Process and Expected Utility of Matrixed data

Knowledge Engineering Process

Knowledge engineering techniques were used to determine military requirements and needs through out the program. The requirements and need listings have been updated and expanded through:

- Participation in meetings, conferences, and symposia
- Interviews with engineers, commanders, and decision-makers

This process led to meetings at Fort Gordon, the Joint Spectrum Center, Fort Huachuca, CECOM, JSTARS JPO, Lincoln Labs and the Army Digitization Office. It was learned that a key difficulty is to accommodate the many IP addresses reliably on the battlefield. It also became apparent that the research undertaken by Drs. Hajek and Madhow at the University of Illinois directly impacts the operational need to service by radio a large current TCP/IP address space and utilize the developing ATM technology.

Another operational need that was identified is that, as the battlefield becomes more active, interference levels on radio links increase. Instead of having a link totally fail, it is important to maintain some capacity on the link for the most important information. One answer coming from the FRI group is to choose codes that inherently have the capability to adapt the channel code rate to the channel conditions. Another was to use a priority schema so that high priority messages can get through first.

Provide government and companies with new technologies communications processes and visions

An outcome of the FRI process is to provide methodologies and solutions that can be used both by industry and by DoD. The FRI process brought together both university researchers and industry engineers and implementers. A joint vision and process resulted from that union. Both sets of participants had the opportunity to "Think Outside the Box". Question the current practices and develop a better understanding of the requirements and needs as expressed by those in DoD.

Thinking outside the box

This process brought students who have never been involved in large-scale communications and communications problems into real world conditions. They, who have not been contaminated by working in the field, could question the practices and requirements. They could really stand back and evaluate the vision and the path chosen to build a tactical communications infrastructure.

The process provided for innovative investigation with the goal of real contributions to both DoD and the commercial sector. It included the following:

Student led research, which permitted university Ph.D. candidates the opportunity to investigate issues that impact both future communications within the military but also commercial communications across the globe

Specific research areas defined between the universities, which permitted the use of individual university expertise, strength and know how in key technology areas

Dual use technology guidance that would provide for greater utility of the research solutions

University expert guidance to the research using world renowned university professors as research advisors and team leaders

Industry's view of applications to commercial and DOD interests using DoD companies to provide commercial and DoD application insight into the solution process

Research Philosophy for FRI Programs

The research efforts were tailored or focused to more closely align with communication requirements, goals or existing problems. Students and their faculty advisors selected topics relevant to the student's interest and emerging or existing technology availability. The industry partners assisted in identifying applications for that research in commercial and DoD venues.

The test bed environment that the FRI helped to establish at Purdue was ideal for technology exchange through step by step demonstrations of increasingly complex technologies. That test-bed was interconnected to Illinois, Michigan and the ARO office.

The research process and topics followed the guidelines of the Army Research Office (ARO) described in two groups as follows: ARO Basic Research Investment Philosophy and Wireless Mobile Communications.

ARO Basic Research Investment Philosophy

- Address Unique Military requirements
 - Infrastructures must be mobile
 - Highly dynamic network topography
 - Highly reliable operation
 - LPI/LPD, AJ
 - Military spectrum
- Leverage Commercial Industry Investments
 - Adaptive antennas
 - Data compression
 - Forward error correcting coding
 - Multiple access techniques
- Build Military LEO/MEO Satellite Systems Based on Commercial Systems
 - Limited capacity in a "region" (+10,000 users in a 3000 km² Division region)
 - Vulnerability due to jamming because of bent pipe designs
 - Denial of service attacks resulting from an open system
 - Useful in low intensity conflicts, special operations or as an augment
- Adapt Commercial Cellular Systems
 - IS-95
 - Need longer code lengths and pilot tone functional replacement to improve LPD/LPI without degrading acquisition/synchronization performance
 - "Hardening" power control algorithms
 - GSM: Utility of frequency hopped mode
 - Performance issues
 - Propagation/Multipath effects at different (higher) frequencies and antenna heights
 - Voice versus data
 - Capacity versus delay
- Frequency Availability
 - Obtain frequency rights in training and deployment regions
 - Frequency translations are non-trivial (Ex.: DirectPC from Ku-band to X-band)

- **Focus Research on What Industry will not do in the Foreseeable Future**
 - Existing and proposed cellular/LEO/MEO communication systems will not meet military requirements without costly, unsolved technical modifications

Mobile Wireless Communications Research Topics of Interest

- **Networks**
 - Multi-hop routing for self-organizing wireless networks with distributed control
 - Highly dynamic topology, traffic loads, and channel conditions
 - Peer to peer, broadcast, and multicast
 - Multilevel security and multiple priority levels
 - Multimedia routing and quality of service
 - Protocol conversion for gateways to heterogeneous networks
- **Links**
 - Source, channel, and modulation coding – e.g., turbo coding
 - Multiple access methods – e.g., code division multiple access (CDMA)
 - Spatial reuse of spectrum (channels) – e.g., beamsteering smart antennas
 - LPI/LPD, AJ properties – e.g., spread spectrum modulation
 - Optimize for low energy – e.g., adjustable data rates and coding
 - Speech, data, image and video compression
- **Modeling and Simulation**
 - Propagation and channel modeling
 - Efficient network simulation
 - Network stability analysis
- **Adaptive Antennas**
 - Mobile (handheld) in addition to (mobile) base station
 - Wide frequency ranges (2 MHz to 10 GHz)
 - Wide signal bandwidths
 - Conformal (vehicle or human)
 - Use of position/location information (GPS)
- **Low Power**
 - Increase capability and mission time of battery powered units (MIRI – Starke)
 - Interaction of devices, signal processing, modulation, coding, protocols, routing, etc.
- **Multi-user Detection**
 - Blind adaptation and interference suppression
 - Reduced complexity algorithms
- **Mobile Ad-Hoc Networks**
 - Protocols and routing
 - Use of position/location information (GPS)
- **Image and Video Compression**
 - Robust to bit errors
 - Multi-resolution

Student Topics and Research Areas

Communications requirements and goals have been obtained through interview, research, and discussion with various Army organizations as well as others. These were developed in light of the research investment philosophies and the mobile communications research topics of interest.

Background of Student Research

The student research areas followed the University research specialties. The advisors were the principle investigators under the FRI and renowned experts in their fields.

Overall Summary of requirements and objectives researched

The research requirements were first matrixed by university focus areas and also matrixed by the requirements and goals developed as part of the study effort. Not all requirements or goals addressed in the research.

Summary of Project Success

What did we achieve with this research coalition? The industry and university advisor team has formed a series of partnerships as a result of the investigations under the FRI. Lee Macmillan, Raytheon Systems Company, has joined forces with Dr. Wayne Starke on communication power issues. Dr. Jim Lehnert, Purdue University, joined the Raytheon team and is working on a DARPA program called GLOMO (Global Mobile Communications). Dr. Bruce Hajek has participated in work and proposals with Raytheon on communications and the Warfighter Internet.

The work done under the FRI is both relevant and an important contribution to the solutions needed on the Tactical Battlefield. The reference charts, which follow, will show the relevancy of the work through a comparison and matching with the requirements and goals defined through the knowledge engineering process.

Reference Charts

The reference charts reflect information about the actual student research and DoD requirements and goals. The charts are the result of data gathering, comparing the requirements and goals with the research that was underway or in completion. The information was gleaned from written research results and student oral presentations to an industry team. The presentation methods on the charts vary to provide a more comprehensive understanding of the results obtained.

Explanation of the Matrices

Communications requirements and goals have been obtained through interview and discussion with various Army organizations. These requirements and goals are those that were specifically identified as important to the organization and its objectives. The requirements matrix is divided into six segments depending upon the specific application the Task Force XXI Brigade (force level communication exercise), Untethered Node Operation, Future Digital Radio, High Capacity Trunk Radio General Communication Requirements, and Information Management.⁴⁶ The requirement or goal resulting from knowledge engineering is identified as a statement supporting the section. A key is provided to identify the source of the requirement or goal. The information on the charts is provided in column fashion. The following describe the column designations and what those designations mean on the various charts. Chart 2 depicts all of the requirements or goals gleaned from the requirements analysis phase with the current updates.

- Chart 2** Column Designations
- Number
 - Declaration as Requirement or Goal
 - Source
 - Requirement or Goal (R or G) Statement
 - University involved in research

Information sources are located at the bottom of each matrix chart. The sources vary from written, stated requirements to interview results. The sources are a result of the knowledge engineering process.

Chart 3 University Matrix

- Requirements and goals compared to university focus or expertise for the research

Chart 4 - Research Matrix

- Actual student research and the requirements or goals met

List List of manuscripts Submitted or Published under ARO Sponsorship

Chart 5 – Requirements by category

- Listing of research requirements by category

Chart 6 – Requirements Matrix for ORD and MNS

- Requirements comparison with selected ORD and MNS documents

Chart 2 – Task Force XXI Brigade Requirements

Categories: TASK FORCE XXI, UNTETHERED NODE, FUTURE DIGITAL RADIO, HIGH CAPACITY TRUNK RADIO, INFORMATION MANAGEMENT, GENERAL

Shown on pages 48-1 to 48-11.

US Army Communication Requirements

Task Force XXI Brigade

#	R or G*	Source	Statement	University
1	R	A, K	Shall manage up to 1200-1400 Computers.	M, P
2	R	A, K	Shall manage up to 800-900 routers/internet controllers.	I, M, P
3	R	A	Shall manage on the move up to 200-300 computers.	M, P
4	R	A	Shall provide on the move operation.	I, M, P
5	R	A	Network shall interface with wireline networks.	I
6	R	B	Shall provide access to WAN.	I
7	G	A	Should provide for video. (Commercial Quality TV=4.8-6.0 Mb/s)	I, M, P
8	R	G, K	Shall support 6000-8000 IP addresses for TFXXI brigade.	I, M, P
9	R	I	Shall provide consistent information services and common user devices from sustaining base to foxhole.	I, M, P
10	R	I, O	Shall provide self-organizing network.	M, P
11	G	K	Should support 30 routing zones. (Probably a SINCGARS artifact)	I
12	G	L	Situational Awareness Accuracy 100M @ speeds up to 45 kph (=minimum update period of 8 sec) Internal to Net	I, M, P
13	G	L	Situational Awareness Accuracy 500M @ speeds up to 45 kph (=minimum update period of 40 sec) Within same Battalion	I, M, P
14	R	L	Shall provide Duplex Needline Grade of Service = 90% QOS=(Successful, On-time Messages)/(Total Messages)	I, M, P
15	R	P	Shall provide QOS=95% for indispensable traffic	I, M, P
16	R	P	Shall provide QOS=90% for critical traffic.	I, M, P
17	R	P	Shall provide QOS=85% for essential traffic.	I, M, P
18	R	L, P	Shall provide situational awareness Speed of Service <4 sec.	I, M, P

- R = Requirement, G = Goal

Untethered Node

(Mobile, Wireless, and Networking Radio: Handheld or Vehicle Mounted)

#	R or G*	Source	Statement	University
19	G	D	Should provide multi-megabit data rates.	I
20	G	D	Should work at ranges >10km.	I, M, P
21	G	D	Should be self organizing.	I, M, P
22	R	D	Shall interface with global commercial communications infrastructure.	I

Future Digital Radio (Preliminary)

#	R or G*	Source	Statement	University
23	R	D	Shall have throughput 100 Kbps – 20 Mbps.	I, M, P
24	R	D	Shall have multi-hop throughput >100Kbps.	I, M, P
25	R	D	Shall provide minimum range of 4 km for on the move.	I, M, P
26	R	D	Shall provide minimum range of 10 km for stationary point to point operation	I, M, P
27	R	D	Shall provide TRANSEC and COMSEC to the Secret level.	I, M, P

Future Digital Radio (Preliminary) Continued

28	R	D	Shall be location aware.	I, M, P
29	R	D	Shall operate a 50-member network minimum.	I, M, P
30	G	D	Should use global virtual resource address space.	I

High Capacity Trunk Radio

#	R or G*	Source	Statement	University
31	R	E (HCTR)	Shall provide 45 Mbps ATM switching On-The-Move. (one end stationary)	I
32	R	E (HCTR)	Shall provide 155 Mbps ATM stationary switching.	I
33	R	E (HCTR)	Shall provide ATM-to-ATM interconnections up to 40 km.	I
34	R	E (HCTR)	Shall operate On-The-Move over land and sea.	I
35	R	E (HCTR)	Shall provide communications between broadband ISDN and narrow band systems.	I
36	G	E (HCTR)	Should minimize multipath effects.	I, M, P
37	R	E (HCTR)	Shall provide BER<10 ⁻⁸ in tactical environment.	I, M, P
38	R	Q	Shall support tunability for wideband frequency allocations.	I, M, P

Information Management

#	R or G*	Source	Statement	University
39	R	A	Shall provide data filters.	I, M, P
40	R	B, Q	Shall provide access to data warehouses. (e.g., GBS) on the move.	I
41	R	A	Shall provide for updating existing data.	I, M, P
42	R	A	Shall prevent data corruption.	I, M, P
43	R	A	Shall provide data fusion.	I, M, P
44	G	B	Should use open software architecture.	I, M, P
45	G	B	Should use common software modules.	I, M, P
46	G	C	Should improve source coding and data compression.	M, P
47	G	E	Should automate data fusion.	I, M, P

General

#	R or G*	Source	Statement	University
48	R	A	Shall work in the presence of commercial traffic.	I, M, P
49	G	A	Should be inconspicuous to commercial world.	I, M, P
50	R	A, I	Shall provide multilevel security.	I, M, P
51	R	A	Shall allow for message prioritization.	I, M, P
52	R	B	Shall provide connectivity to legacy systems.	I, M, P
53	G	C, D	Should provide LPI.	M, P
54	G	C, D	Should provide jamming resistance.	M, P
55	R	C	Shall work in continuously varying network topography.	I, M, P
56	G	C	Should adapt channel coding to maximize throughput for existing conditions.	I
57	G	F (7.3)	Should implement an adaptive FEC based on requested quality of service.	M, P
58	R	H	Shall provide automatic adaptive FEC.	M, P

General Continued

#	R or G*	Source	Statement	University
59	R	F (7.1)	Shall provide dynamic routing.	I, M, P
60	G	F (7.1)	Should implement a network wide domain naming service.	I, M, P
61	G	F (7.1).1	Should support standard naming and addressing.	I, M, P
62	G	F (7.3).1	Should allow all users "communications on the move".	I, M, P
63	R	F (7.3)	Shall provide dynamic bandwidth allocation.	I, M, P
64	R	I, Q	Shall provide capability to allocate and apportion communication resources.	I, M, P
65	G	F (7.4)	Should automate network management.	I, M, P
66	R	G, Q	Shall provide dynamic network reconfiguration.	I, M, P
67	R	G, I	Shall provide tactical video conferencing.	I, M, P
68	R	I	Shall provide multi-media platform services.	I, M, P
69	R	I	Shall support force and split based operations.	I, M, P
70	R	I	Shall support joint (multi-service) and combined (multi-national) operations	I, M, P
71	R	C	Shall provide transfer of digital data.	I, M, P
72	G	C	Should provide digital transfer of speech, video, image, text and binary data,	I, M, P
73	G	I	Should support situational awareness.	I, M, P
74	G	I	Should support internet.	I
75	G	I	Should support voice mail.	I, M, P
76	G	I	Should support imagery.	I, M, P
77	G	I	Should support messaging.	I, M, P
78	G	I	Should support distributed databases.	I, M, P
79	G	I	Should support distributed processing.	I, M, P
80	R	J	Shall provide confidentiality (Privacy of data with encryption to protect information from unauthorized disclosure).	I, M, P
81	R	J	Shall provide availability (Ensuring systems resources are safeguarded from tampering and available for authorized users).	I, M, P
82	R	J	Shall provide identification and authentication (Verification of originator for transaction).	I, M, P
83	R	J	Shall provide data integrity (Absolute verification that data was not modified during transmission or data processing).	I, M, P
84	R	J	Shall provide non-repudiation (Undeniable proof of participation by both sender and receiver in a transaction).	I, M, P
85	R	M	Commercially supported standards with validated implementations available in multiple vendor mainstream commercial products shall take precedence.	I, M, P
86	R	M	Basic file transfer shall be accomplished using File Transfer protocol (FTP).	I, M, P
87	R	M	Basic remote terminal services shall be accomplished using TELNET.	I, M, P
88	R	M	Hosts shall implement the Simple Network Management Protocol (SNMP) set of network management protocols.	I, M, P
89	R	M	Variable Message Format (VMF) messages shall use a connectionless application layer with UDP transport service.	I, M, P

General Continued

#	R or G*	Source	Statement	University
90	R	M	To support large VMF messages transmitted or received over Combat Net Radio (CNR), message segmentation and re-assembly shall also be implemented.	I, M, P
91	R	M	For multi-addressed VMF messages transmitted or received over CNR, Selective Directed Broadcast shall also be implemented.	I, M, P
92	R	M	TCP shall implement the PUSH flag and the Nagle Algorithm, as directed in IAB Standard 3.	I, M, P
93	R	M	VTC terminals operating at data rates of 56-1920 kbps shall comply with the industry profile for Video Tele-conferencing VTC001.	I, M, P
94	R	M	VTC terminals operating at low bit rate (9.6-28.8 kbps) shall comply with ITU-T H.324.	I, M, P
95	R	M	Facsimile terminals operating in tactical, high bit error rate environments shall implement digital facsimile equipment standards for Type I and/or Type II mode.	I, M, P
96	R	M	Facsimile transmissions requiring encryption shall use the digital facsimile standards.	I, M, P
97	R	M	TAC02 shall be used over point to point tactical data links in high Bit Error Rate (BER) disadvantaged communications environments.	I, M, P
98	R	M	Routers shall use the Open Shortest path First (OSPF) V2 protocol for Unicast interior gateway routing and Multicast OSPF (MOSPF) for multicast interior gateway routing.	I, M, P
99	R	M	Routers shall use the Border gateway Protocol (BGP) V4 for exterior gateway routing.	I
100	R	M	With the exception of High Frequency (HF) networks, MIL-STD-188-220A shall be used as the standard communications net access protocol for CNR networks.	I, M, P
101	R	M	Link 16 messages comprised of J-series formats shall be used for information transfer with information systems and/or weapons platforms that use both the Joint Tactical Information Distribution Systems (JTIDS) and UHF, or SATCPOM suite of media.	I, M, P
102	R	M	Link 22 messages comprised of F-series formats shall be used for the exchange of maritime operational data between tactical data systems using line of sight (UHF) and beyond line of sight (UHF) bands.	I, M, P
103	R	M	AAL1 (ATM Adaptation layer) shall be used to support constant bit rate service, which is sensitive to cell delay, but not cell loss.	I, M, P
104	R	M	AAL5 shall be used to support variable bit rate service.	I, M, P
105	R	M	The J-series family of message standards shall be used to satisfy all tactical data link requirements.	I, M, P
106	R	M	TADIL messages comprised of J-series formats shall be used for information transfer with information systems and/or weapons platforms that use both (JTIDS) (or MIDS when available) and UHF, or SATCOM suite of media.	I, M, P

General Continued

#	R or G*	Source	Statement	University
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107	R	M	Variable message format (VMF) comprised of messages using K-series format shall be used to exchange information with forward units of the battlespace.	I, M, P
108	R	M	Link 22 is comprised of F-series formats and shall be used for the exchange of maritime operational data between tactical data systems using line of sight (UHF) and beyond line of sight (HF) bands.	I, M, P
109	R	M	DoD systems shall have adequate safeguards to enforce DoD security policies and system security procedures.	I, M, P
110	R	M	System safeguards shall provide adequate protection from user attempts to circumvent system access control, accountability, or procedures for the purpose of performing unauthorized system operations.	I, M, P
111	R	M	C4I systems shall comply with class C2 requirements as defined in DoD 5200.28-std.	I, M, P
112	R	M	If digital signature is required, the following standard shall be used: FIPS PUB 186, Digital Signature Standard, NIST, may 1994.	I, M, P
113	G	M	A mobile host should not have to perform any special actions because of host migration. (Mobile Host Protocol)	I, M, P
114	R	N	Shall provide Military Intelligence 640 Kb/s for imagery between Division and Brigade MI Element.	I, M, P
115	R	N	Shall provide Military Intelligence 128 Kb/s for imagery between Brigade MI Element and 5 battalion TOCs.	I, M, P
116	R	O	Shall provide electronically steerable antennas for communication on the move and precise stationary pointing.	P
117	R	O	Shall work efficiently with 256-512 Kb/s radios.	I, M, P
118	R	Q	Shall integrate dismounted soldier into digital battlefield.	I, M, P
119	R	Q	Shall have soldier radio with 1.3-Km range.	I, M, P
120	R	Q	Shall have squad radio with 5-Km range.	I, M, P
121	R	Q	Shall have Squad radio that is SINCGARS SIP compatible.	I, M, P
122	R	Q	Shall have GPS inside buildings.	I, M, P
123	R	Q	Shall provide narrow band mobile IP host support in hostile environment.	I
124	R	Q	Shall provide bent pipe airborne relay with full duplex 45 Mbps link.	I, M, P
125	R	R	Shall provide total protection from nuisance threats: disposable jammers; <10 watts at 25-50 miles.	I, M, P
126	R	R	Shall provide protection for principal communication from small tactical jammers: 100-200 watts at 50 miles.	I, M, P
127	G	S	Should provide soldier query mechanisms for data.	P
128	G	S	ACN should provide sufficient battlefield coverage to augment the spaceborne and other airborne nodes.	I
129	G	S	Should use the Warfighter Internet to provide the connectivity and backbone for battlefield communications.	I
130	R	T	Shall support large communication data flows between JSTARS and its ground elements.	I, M, P
131	R	T	Shall provide for line of sight and beyond line of sight capability for JSTARS and its ground elements.	

General Continued

132	R	T	Shall have a reach back capability for user requests.	P
133	R	T	Lower echelon users shall have real-time MTI capability.	I, M, P
134	R	T	Echelon above Corps shall have battle damage assessment data.	I, M, P

Future Digital Radio Updated Requirements

This is update of the FDR requirements listed in #25-38.

#	R or G*	Source	Statement	University
135	R	U	Shall perform routing functions within its autonomous network (T).	I, M, P
136	R	U	Shall operate successfully on vehicles moving at 50-mph (T).	M, P
137	R	U	Shall have embedded capability for obtaining their own position location reports that are accurate to within 30 meters (T) to 3 meters (O) Circular error Probable within a nominal 47-km x 47-km area.	
138	R	U	Display position reports at both radio and host locations	
139	R	U	Shall provide means to accommodate user-defined message precedence assignments and to dynamically allocate/re-allocate network capacity based on message precedence and user-defined host system priorities (T).	M
140	R	U	Shall provide means to remotely distribute current and next crypto-period system keys over FDR circuits from control or management facilities to user radios (T).	
141	R	U	Shall provide means for invoking zeroization or selective exclusion from the network of individual radios over the air from network control facilities (T).	
142	R	U	Shall provide a means, both locally and through FDR D2 network links, to effect changes to initialization, COMSEC, and TRANSEC loads of any radio in an autonomous FDR D2 network (T).	
143	R	U	Shall provide means to assess and report network link status to ISYSCON (T).	
144	R	U	Shall provide means for FDR network management facilities to program FDR nodes to automatically transmit individual position reports over the FDR network to selected FDR nodes (T).	
145	R	U	Shall provide connectivity for an autonomous network of 400 (T) to 900 (O) FDR nodes tactically deployed in a nominal 20-km by 30-km area.	I, M, P
146	R	U	Shall provide connectivity across autonomous networks for 900 (T) to 2000 (O) FDR nodes tactically deployed in a nominal 47-km x 47-km area.	I, M, P
147	R	U	Shall provide routing service within an autonomous network for all user-to-user requirements including broadcasts from any FDR node to 150 (T) to 900 (O) FDR nodes.	I

Future Digital Radio Updated Requirements

#	R or G*	Source	Statement	University
148	R	U	Shall provide means to support dynamic address changes after the network is initialized without having to reload initialization files (T).	
149	R	U	Shall provide for COMSEC and protection of data classified Secret (T) to Top Secret (O).	
150	R	U	Shall maintain network grade of service in autonomous networks while 10% (T) to 100% (O) of FDR nodes are simultaneously moving at speeds of at least 50 mph.	
151	R	U	Shall provide means to establish and sustain broadcasts at rates of 288 Kbps (T) to 20 Mbps (O).	
152	R	U	Shall provide means to establish and sustain point-to-point circuits to accommodate transmission of 144 kbps (T) to 10 mbps (O) while simultaneously receiving 144 kbps (T) to 10 mbps (O).	
153	R	U	Shall in the absence of Electronic Warfare (benign) conditions establish and sustain connectivity for 85% (T) to 100% (O) of assigned and operationally available radios in a brigade autonomous network.	
154	R	U	Shall in benign conditions, successfully deliver 90% (T) to 100% (O) of Information Exchange Requirements (IERs) submitted to the network.	
155	R	U	Shall in benign conditions, insure that 90% to 100% of delivered IERs meet Speeds Of Service (SOS) defined for IERs.	
156	R	U	Under postulated Threat electronic warfare (EW) conditions, the FDR D2 system shall establish and sustain connectivity for 70% (T) to 100% (O) of assigned and operationally available radios in a brigade autonomous network.	M
157	R	U	Shall under EW conditions successfully deliver 90% (T) to 100% (O) of IERs submitted to the network.	
158	R	U	Shall under EW conditions, ensure that 90% (T) to 100% (O) of delivered IERs meet three times (T) to one time (O) the Speeds of Service (O).	
159	G	U	Should have size, power and weight comparable to EPLRS (O).	
160	R	U	Shall survive High Altitude Electromagnetic Pulse (HAEMP) (T).	
161	R	U	Shall provide operator level power-up Built-In-Test (BIT) capability for testing to determine if radio is functional (T).	

T = Threshold, O = Objective

Wideband Data Network

#	R or G*	Source	Statement	University
162	R	V	Shall support mixed traffic including data, voice, and video with the capability for packet multiplexing.	P
163	R	V	Shall support an information bit rate of 1 to 10 Mbps (or greater) where the information rate is the user (source) data rate which excludes any overhead such as FEC, any framing bits, synchronization, preambles, and networking overhead.	
164	R	V	Shall provide variable QOS to support graceful performance degradation under varied traffic loading, geographic dispersion, mobility, terrain, and EMI conditions by utilizing adaptive protocol features.	I
165	R	V	The network waveform shall support mobility and not rely on any fixed communication infrastructure.	P, M
166	R	V	Shall provide brigade-wide radio network communications.	
167	R	V	Shall provide operation over BGE area ranging from 15 x 15 to 150 x 150 km, with up to 400 radios on vehicles with speeds up to 80 km/hr.	
168	G	V	It is desired that the waveform be useable on avionics platforms at speeds of 80-320 km/hr.	P, M
169	R	V	Shall provide autonomous network organization with automated and adaptive routing, organization management, and address/mobility management.	I
170	R	V	Shall provide address/mobility management that avoids host IP address reassignment.	I, M, P
171	R	V	Shall provide remote network management.	I, M, P
172	R	V	Shall provide the QOS and SOS as defined in the Traffic Requirements Table.	I, M, P

Traffic Requirements Table

Traffic Type	Network Service	Typical Message Size	QOS	SOS
Battle Command Data	IP Unicast and Multicast	100 – 500 bytes	95%	0.5 sec
Situation Awareness Data	IP Broadcast	100 bytes	95%	5 sec

Report on Emerging Technologies

#	R or G*	Source	Statement	University
173	R	W	Network management must be automatic and background.	I
174	R	W	Network management must take account of bandwidth limitations.	P, M
175	R	W	Network management must take account of priorities.	I, M, P
176	R	W	Network management must take account of naming and addressing.	I, M, P

Report on Emerging Technologies (Continued)

177	R	W	Network management must evolve to support a mix of systems yet provide for autonomous operation.	I, M, P
178	R	W	Network management must allow traffic flow to be guided by current mission priorities.	I, M, P
179	G	W	Wireless LANs should support data rates of > 100 MBPS.	I
180	R	W	Adaptive antennas must handle J/S ratios of 30 dB or more.	P
181	R	W	Wireless LANs must support mobility.	I
182	R	W	New Protocols must support mobile operations.	P
183	R	W	Wireless LANs must operate from a few km to 10 km.	I, M, P
184	R	W	Future systems must provide a coherent approach to security.	
185	R	W	New protocols must address vulnerability to Information Warfare.	P
186	R	W	New systems (codes) must overcome problems with spoofing.	I, M, P
187	R	W	Network management must address the security requirements of control and monitoring of information.	I, M, P
188	R	W	Traditional approaches to security will not work in a multicast environment. An alternative paradigm must be developed.	
189	R	W	Future systems must use a COE.	
190	R	W	Military systems must make optimal use of commercial technology.	
191	R	W	Future antennas must be multi-mode, multi-band to allow more systems to be on the same platform.	P
192	R	W	New protocols must work in low bandwidth, high error environments.	P
193	G	W	New radios should employ general-purpose signal processors to allow field software updates to quickly upgrade radios.	
194	R	W	Systems must infer/identify the cause of service degradations.	

Future Operational Capability

#	R or G*	Source	Statement	University
195	G	X	Information architecture should be dynamic, self-organizing, self-healing and modular.	I, M, P
196	G	X	Should be able to transfer information within the architecture without specific knowledge of the platform that makes up the automatic system.	
197	G	X	Provide automated network planning including placement of resources against subscriber requirements, terrain conditions, tactical restrictions and COMSEC requirements.	P
198	G	X	Provide automatic spectrum management that eliminates cosite effects and provides maximal use of available bandwidth, including bandwidth on demand when appropriate,	P
199	R	X	Future military systems must include legacy (old) systems.	

Future Operational Capability

200	R	X	Future systems must work with mix of WAN, LAN, mobile, and ally surface/satellite communications (to include commercial systems).	I, M, P
201	R	X	Provisions must be made to extend global fiber optic infrastructure into the theater of interest.	
202	G	X	Information architecture should be compatible with the JTA and COE.	

Source Key

Key	Source
A	Interview @ Fort Gordon 10/13/95 with Col. Forester, Col. Lusk
B	AFCEA Proceedings of the 20 th Annual Symposium, The Digitization of Force XXI, September 12-14, 1995.
C	RFP for Wireless, Distributed Multimedia
D	TRP, Digital Wireless Communications & Networking Systems
E	Advance Planning Briefing for Industry, Oct. 11-12, 1995
F	MILCOM 95
G	M. Giordano's Comments at Signal XXI
H	Concept Paper by Tony Loop
I	Warfighter Information Network Brief
J	Multilevel Security Brief
K	Tactical Internet Brief
L	Modeling & Simulation: ADO study
M	Department of Defense Joint technical Architecture 4/26/96
N	Fort Huachuca Visit (Dr. Poesel)
O	Fort Leavenworth Visit (Col. Lamar)
P	TF XXI (ADO) Study, Modeling & Simulation Report
Q	MURI Kickoff meeting
R	ABIS Task Force Report
S	Lincoln Laboratory (MIT) Meeting 7 May 1998, Lexington, MA
T	JSTARS Meeting 8 May 1998, Hansom AFB, MA
U	Operational Requirements Document for the Future Digital Radio (FDR), Coordinating Draft, 14 February 1997
V	Wideband Tactical Data Radio Networks, CECOM BAA 5 August 1997
W	TTCP STP-8 report on Emerging Technologies 11/96
X	TRADOC Pamphlet 525-66 Future Operational Capability

Chart 3 - University Matrix

Requirements and goals are compared to the university focus or expertise for that research. The numbers on the left refer to the requirement numbers, which coincide with those in chart 2. The numbers under the universities refer to the publications, which are listed by number under the "List of Manuscripts Submitted for Publication", page 51.

The University matrix is shown on the following pages 49-1 to 49-6.

Requirement #	Michigan	Purdue	Illinois
1			
2			
3			
4		38, 44, 46, 56	
5			
6			
7			
8			
9		5, 6, 51, 56	
10			
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18			
19		54	
20			
21		36	
22		56	
23			7
24			7
25		5, 6, 51, 52, 53, 56	
26			
27			
28			
29			
30			
31		146	
32		146	
33			
34		15, 18, 20, 21, 23, 24, 25, 27, 29, 30, 38, 44, 50, 56, 146	
35			
36	10	15, 18, 23, 24, 27, 29, 40, 48, 49	
37		15, 18, 23, 24, 27, 29, 54, 55, 180	

Requirement #	Michigan	Purdue	Illinois
38			
39			
40			
41		180	
42			
43			
44			
45			
46	8, 9		
47			
48		20, 21, 25, 30, 50, 56	
49		20, 21, 25, 30, 50, 56, 146	
50			
51			2
52			
53	8, 9		7
54	14	15, 17, 18, 19, 20, 21, 23, 24, 26, 27, 28, 29, 30, 31, 39, 42, 43, 45, 47, 53, 146, 147	
55	11	15, 18, 22, 23, 24, 27, 29, 48, 49, 56	
56	9, 10, 11, 12	6, 15, 16, 18, 20, 21, 23, 24, 25, 27, 29, 30, 48, 49, 50, 56	
57		32, 33, 34	
58		15, 18, 20, 21, 23, 24, 25, 27, 29, 30, 50, 54, 56	
59	13	5, 32, 33, 34, 54, 56	2
60		56	2
61			
62		5, 6, 32, 33, 34, 48, 49, 51, 52, 53, 56	2
63			
64		20, 21, 25, 30, 56	
65	11	15, 18, 23, 24, 27, 29, 54, 56	1, 2

Requirement #	Michigan	Purdue	Illinois
66	1	5, 6, 15, 18, 23, 24, 27, 29, 48, 49, 51, 52	
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71	3		
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84		21, 30	
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Requirement #	Michigan	Purdue	Illinois

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116		17, 35, 48, 49, 55	
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125		15, 18, 23, 24, 26, 27, 29, 53	
126		15, 18, 23, 24, 26, 27, 29, 53	
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165	12	15,18, 23	
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168	8		
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202			

The numbers under the universities refer to publications or documents produced under the FRI which support the requirement number listed in the left column.

Chart 4 - Research Matrix

The actual student research areas and the requirements addressed for this program are presented here along with information about some of the research and its applicability to both commercial and DoD applications.

The student research information is shown on the following pages 50-1 to 50-6.

Student Research Matrix

Michigan University Dr. Wayne Starke, Principle Investigator

Requirements addressed: 46, 53, 54, 55, 56, 195

Student Researchers-Professor

Victor Cheng - Dr. Starke

Multicast, Multimedia Spread Spectrum Architecture

Requirements: 46, 53, 55, 195

Joseph Kang

Turbocodes for Non-coherent FH-SS with partial band Interference

Requirements: 46, 54, 56

Sang Wu Kim

Performance Limits of Reed-Solomon Coded CDMA with Orthogonal Signaling in a Rayleigh Fading Channel

Requirements: 46, 56

Abdulrauf Hafeez

Decision feedback Sequence Estimation for Unwhitened ISI and Multi-user CDMA Channels

Requirements: 55, 56

Purdue University Dr. James Lehnert, Principle Investigator
FRI Program Manager

Requirements addressed: 9, 25, 34, 35, 36, 37, 48, 49, 54, 55, 56, 57, 58, 59, 62, 64, 65, 66, 116, 125, 126, 146

Student Researchers-Professor

Der-Feng Tseng - Dr. Zoltowski

- Narrow band digital communications - two antennas
- Frequency selective multi-path channels
- Blind Channel Identification scheme - to do equalization
- On the use of Basis Functions in Blind Equalization Based on Deterministic Least Squares

Requirements: 36, 55, 56, 62, 66, 116, 146

Yung-Fang Chen

- Blind 2-D rake receivers Based on Space Time Adaptive MVDR Processing for IS-95 CDMA System
- Convergence Analysis and Tracking Ability of Reduced Dimension Blind
- Space-Time Rake receivers for DS-CDMA

- Joint Angle and Delay estimation for Reduced Dimension Space-Time Rake
- receiver with Application to IS-95 CDMA uplink
 - Direct sequence spread spectrum - uplink/reverse link - 2 antennas
 - Blind space time RAKE receiver
 - No training symbols

Requirements: 57, 59, 62, 146

Tsao-Tsen Chen - Dr. Lehnert

- Multi-user Decision-Feedback receivers for Asynchronous CDMA Systems over a Mismatched Rayleigh Fading Channel
- TCM/SSMA Communication Systems with Cascaded-Sequences and PAM/QAM
- Signal Sets
- Bounds on the Pairwise Error Probability of Coded DS/SSMA Communication
- Systems in Rayleigh Fading Channels
- Cumulative Distribution Function of the Two-Dimensional Multiple-Access
- Interference in DS/SSMA Communication Systems
- Coded DS/SSMA Communication Systems over fading Channels

Requirements: 34, 36, 37, 54, 55, 56, 58, 65, 66, 125, 126

J. Chao New Researcher

James Qian Zhang

- Performance of a Type-II Hybrid ARQ Protocol in Slotted DS-SSMA Packet radio Systems
- Adaptive Coding for Slotted DS-SSMA Packet radio Systems
- Stability Analysis of Type-II Hybrid ARQ protocol in Slotted DS-SSMA Packet
- Radio Systems

Requirements: 34, 48, 49, 56, 58, 64

Shiau-he Tsai New Researcher

Junyi Li - Dr. Edward Chong

- Packet Switched Networks reduce inter and intra cell interference
- Power level control in networks

Requirements: 9, 25, 62, 66

Jing Yu

- Dynamic Channel Allocations with two base stations controlling power by letting each base alternate as lead

Requirements: 25, 62, 66

Tan Wong

- SS correlation improvement through sampled outputs
- Interference excision techniques - space time adaptive
- Techniques to take out jammers

Requirements: 54, 125, 126

Jeff Heffner

- Wireless communications power control - distributed power
 - Base station assignment and channel assignment algorithm
 - Treats any other user as an interferer
 - Joint Power control and base station assignment - asynchronous
 - Signal to interference ratio feasibility - mobile to base link

Requirements: 25, 54, 62, 125, 126

University of Illinois Dr. Bruce Hajek, Principle Investigator

Requirements addressed: 4, 9, 22, 25, 34, 37, 48, 49, 51, 55, 57, 58, 59, 60, 62, 65, 97, 116, 139, 175

Student Researchers

Vijay Subrainanian

- Direct Sequence Spread spectrum - matched filter receiver
- Multiple receiver array
- TDMA IS136 standard - space time codes - signal correlation by offset

Requirements: 37, 116

Hermet Chaska

- Wireless link Shaping for service guarantee over heterogeneous networks
- Link shaping
- QOS service

Requirements: 4, 9, 22, 25, 34, 48, 49, 55, 57, 58, 59, 60, 62, 65, 97

Pierre Seri

- Deadlines, prioritization and scheduling for PCS and Cellular Systems

Requirements: 51, 59, 60, 62, 65, 139, 175

Julian Waldby

- Congestion Control
- Scaling based on missing packets
- Error recovery

Requirements: 37, 58, 59, 65

Program Results Summary

List of Manuscripts Submitted or Published under ARO Sponsorship

These manuscripts are relevant to ARO's goal of providing information that is applicable to both the Commercial and DoD community.

The manuscript listing is shown on pages 51-1 to 51-6.

1997 List of Manuscripts Submitted or Published under ARO Sponsorship

1. B. Hajek, A. Krishna, R. O. LaMaire, "On the capture probability for a large number of stations," *IEEE transactions on Communications*, vol. 42, pp. 254-260, February 1997.
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1997-1998 Research Topics Underway

50. Purdue – James Qian Zhang – Dr. James Lehnert Advisor
Performance of a Type II Hybrid ARQ protocol in Slotted DS-SSMA packet radio systems
Adaptive Coding for slotted DS-SSMA packet radio systems
Stability analysis of Type-II Hybrid ARQ protocol in slotted DS-SSMA packets
Radio Systems
51. Purdue - Junyi Li –Dr. Edward Chong, advisor
Packet Switched Networks reduce inter and intra cell interference
Power Level control in networks
52. Purdue – Jing Yu – Dr. Edward Chong, advisor
Dynamic channel allocations with two base stations controlling power by letting each base alternate as lead
Power level control in networks
53. Purdue – Jeff Heffner – Dr. Edward Chong, advisor
Wireless communications power control – distributed power
Base station assignment and channel assignment algorithms
Joint power control and base station assignment – asynchronous
Signal to interference ratio feasibility – mobile to base link
54. Illinois – Julian Waldby – Dr. Bruce Hajek, advisor
Congestion control
Scaling based on missing packets
Error recovery

55. Illinois – Vijay Subrainanian – Dr. Bruce Hajek, advisor
Direct sequence spread spectrum – matched filter receiver
Multiple receiver array
TDMA IS136 standard – space time codes – signal correlation by offset
56. Illinois – Hermet Chaska – Dr. Bruce Hajek, advisor
Wireless link shaping for service guarantee over heterogeneous networks
Link shaping
QOS service

Chart 5 - Requirements by Category

Listing of research requirements by category

Grouped by Category: AUTONET, CONNECTIVITY, DATA RATE, LPI_AJ, NETSIZE, OTM, RANGE, SECURITY, SIT_AWARENESS, and STANDARDS

The requirements by category charts are shown on the following pages 52-1 to 52-7.

Requirements by Category

Under each category is the requirement number from Chart XX.

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
1					X						
2					X						
3					X						
4						X					
5		X									
6		X									
7			X								
8					X						
9											
10	X										
11					X						
12									X		
13									X		
14											X
15											X
16											X
17											X
18									X		
19			X								
20							X				
21	X										
22		X									
23			X								X
24							X				
25							X				
26								X			
27											
28											X

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
29					X						
30											X
31			X								
32			X								
33							X				
34						X					
35		X									
36											X
37											X
38											X
39											X
40						X					
41											X
42								X			
43											X
44									X		
45										X	
46											X
47											
48				X							
49				X							
50								X			
51											X
52		X									
53				X							
54				X							
55	X										
56	X										
57	X										
58	X										
59	X										

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
60											X
61											X
62						X					
63	X										
64	X										
65	X										
66	X										
67											X
68											X
69											X
70											X
71											X
72											X
73									X		
74											X
75											X
76											X
77											X
78											X
79											X
80								X			
81								X			
82								X			
83								X			
84								X			
85										X	
86										X	
87										X	
88										X	
89										X	
90										X	

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
91										X	
92										X	
93										X	
94										X	
95										X	
96										X	
97										X	
98										X	
99										X	
100										X	
101										X	
102										X	
103										X	
104										X	
105										X	
106										X	
107										X	
108										X	
109								X			
110								X			
111								X			
112								X			
113	X										
114			X								
115			X								
116						X					
117			X								
118											X
119							X				
120							X				
121		X									

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
122									X		
123											X
124			X								
125				X							
126				X							X
127											X
128											X
129											X
130											X
131											X
132											
133									X		
134									X		
135	X										
136					X				X		
137											
138											X
139	X							X			
140								X			
141								X			
142											
143	X										
144	X										
145					X						
146					X						
147	X										
148	X										
149								X			
150						X					
151			X								
152			X								

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
153		X									
154		X									
155		X									
156		X									
157		X									
158		X									
159										X	
160										X	
161										X	
162			X								
163			X								
164			X								
165	X										
166	X										
167							X				
168							X				
169	X										
170	X										
171	X										
172		X									
173	X										
174	X										
175	X										
176	X										
177	X										
178	X										
179			X								
180				X							
181									X		
182									X		
183							X				

Rqmt #	AUTONET	Connectivity	Data Rate	LPI_AJ	Net Size	OTM	Range	Security	Situation Awareness	Standards	Other
184								X			
185								X			
186								X			
187								X			
188								X			
189										X	
190										X	
191										X	
192										X	
193										X	
194										X	
195	X										
196	X										
197	X										
198	X										
199		X									
200		X									
201		X									
202										X	

Chart 6 – Requirements Matrix for ORD and MNS

The following chart maps the USAF ORD and MNS requirements against the FRI developed overall requirements listing.

Requirements Matrix for USAF ORD and MNS

Reference Number	Name	System Capability/Characteristic	Research/Manuscript Number*
AIA MNS 003-95	Operational Defensive Counter-information Warfare Capability, MNS	Protect C ⁴ I Systems	2, 3, 11, 12, 14, 15, 18, 19, 23, 25, 36
JORD 301-95	Joint CAF-USA, USMC, USN CAPSTONE for the Common Imagery Ground Surface Station, JORD	Electronically receive, transmit, and disseminate high-quality imagery intelligence (IMINT) products	2, 3, 11, 12, 14, 15, 18, 19, 23, 25, 36
CONOPS for CIGSS	Interoperability Among Common Imagery Ground Surface Systems (CIGSS)	Near Real-time Imagery	2, 3, 11, 12, 14, 15, 18, 19, 23, 25, 36
CAF (USAF) 007-89	Tactical Secure Data Communications, ACC ORD	Secure Communications	7, 8, 9, 10, 12, 14, 15, 18, 19, 23, 24, 25, 27, 28, 39, 40, 42, 43, 45, 47, 48, 54, 55, 56
CAF 315-92	Real-time Information in the Cockpit, MNS	Real-time information to the cockpit	15, 19, 36
CAF 311-92-1-B	Theater Deployable Communications, ORD	Deployable communications	5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 21, 22, 23, 27, 36, 50, 54, 55, 56
CAF 306-94-I/II/III-A	Tactical Information Broadcast Service (TIBS), ORD	Information Dissemination	2, 3, 9, 11, 12, 14, 15, 18, 19, 25
USAF 004-91	Theater Missile Defense, CAF MNS	Theater Missile Defense	2, 3, 11, 12, 14, 15, 19, 25, 27, 36

*Refer to project research requirements listing on page 47.

Summary or Conclusion

Benefits to ARO

Impact on Defense

This research will aid in the development of a comprehensive communication system to support the digitized battlefield of the future. The increasing pace of action and the rapidity of movement on the battlefield, coupled with the limited availability of RF spectrum, even today strains the ability to access necessary information from databases of the Army's main Battlefield Functional Areas. (Maneuver Control, Air Defense, Artillery Fire Control, and Intelligence and Electronic Warfare).⁴⁷ This condition will only be exacerbated in the future, as the need increases to transmit more data, including reconnaissance imagery and sensor video, to combat platforms, command posts, analysis centers, and individual personnel. Cooperative engagement tactics are dependent upon the sharing of data and imagery among multiple platforms and agencies, giving each a common view of the battlespace.^{48, 49} A successfully designed and implemented multimedia system can become a great amplifier for the soldier prosecuting the battle.⁵⁰ Access to the latest data and imagery while on the move will improve his effectiveness by directing him to high priority targets with complete knowledge of the target's status and the status of his supporting units. More rapid access to databases will also reduce the problem of units being out of position because of lack of information about their environment and of misidentification of friendly units, especially when they are encountered in unexpected places. With proper access to the war-fighting databases and near real-time updates, situations involving "friendly fire" can be prevented.⁵¹

The research will help clarify the basic requirements for distributed military networks, and thereby help steer commercial development in network technology towards meeting the needs of the military. For example, our goal to design TCP-like adaptive end-to-end congestion control mechanisms, which are suitable for a heterogeneous network with wireless links, could help TCP/IP evolve into a more effective dual-use technology. The research on integration of coding, modulation, and retransmission algorithms will aid the design of more robust and higher capacity spread-spectrum radio links. The research on adaptive antenna arrays will enhance LPI, while increasing bandwidth efficiency via spatial re-use. Our research on routing protocols that adapt their time constants to the level of mobility displayed by the networks, and retransmission strategies that exploit large buffers to ensure survivability, will indicate how to enhance the robustness of present-day military networks.

Benefits to University

The research has had specific benefits to the universities involved. The benefits include:

- Research relevancy – solve real world problems
- Dual use research – commercial and DoD applications

The research, entailing interaction between universities and industry, has had a significant impact in strengthening and maintaining strong graduate and undergraduate curricula in communications, networking, and signal processing at the three major research universities

involved. Furthermore, between fourteen and roughly twenty-five graduate students can be expected to obtain excellent research exposure through participation in this research effort.

Benefits to Industry

Impact on Commercial Systems

The basic research will help provide the conceptual underpinnings, algorithms, design techniques and performance evaluation techniques for the development of ambitious commercial systems, including:

- (1) Personal communication systems, which enable individuals, whether walking indoors, walking outdoors, or traveling in vehicles, to maintain constant multimedia connectivity to wireline networks;
- (2) Multiple satellite communication systems, employing up to hundreds of packet-switched, low-earth-orbit satellites to provide robust, continuous worldwide connectivity for integrated voice/data communications; and
- (3) Advanced vehicle control systems, designed to make roadways in dense urban environments more efficient by relying on communications provided by a combination of roadway cells and self-organizing networks formed from platoons of vehicles.

The research in adaptive coded modulation and antenna arrays will increase the efficiency of both spread-spectrum and narrow-band wireless systems in terms of bandwidth and power, two critical commercial resources. The research on routing and congestion control for multimedia traffic in wireless networks will enhance present day commercial cellular networks, while enabling the design of more flexible network architectures based on an amalgam of the cellular and self-organizing paradigms. Finally, the research on the design of the interface between wireless and wireline networks will answer urgent commercial needs for new protocols that enable mobile users to interface with backbone networks such as the TCP-based Internet or an ATM-based wide area network.⁵²

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Table of Acronyms

ACN	Airborne Communications Node
ATM	Asynchronous Transfer Mode
BLOS	Beyond Line Of Sight
CNR	Combat Net Radio
GBS	Global Broadcast System
HCTR	High Capacity Trunk Radio
ISR	Intelligence, Surveillance, and Reconnaissance
LAN	Local Area Network
LEO	Low Earth Orbit
MEO	Medium Earth orbit
MSE	Mobile Subscriber Equipment
PCS	Personal Communication System
RAP	Radio Access Point
TI	Tactical Internet
WAN	Wide Area Network
WI	Warfighter Internet
WIN	Warfighter Internet Network